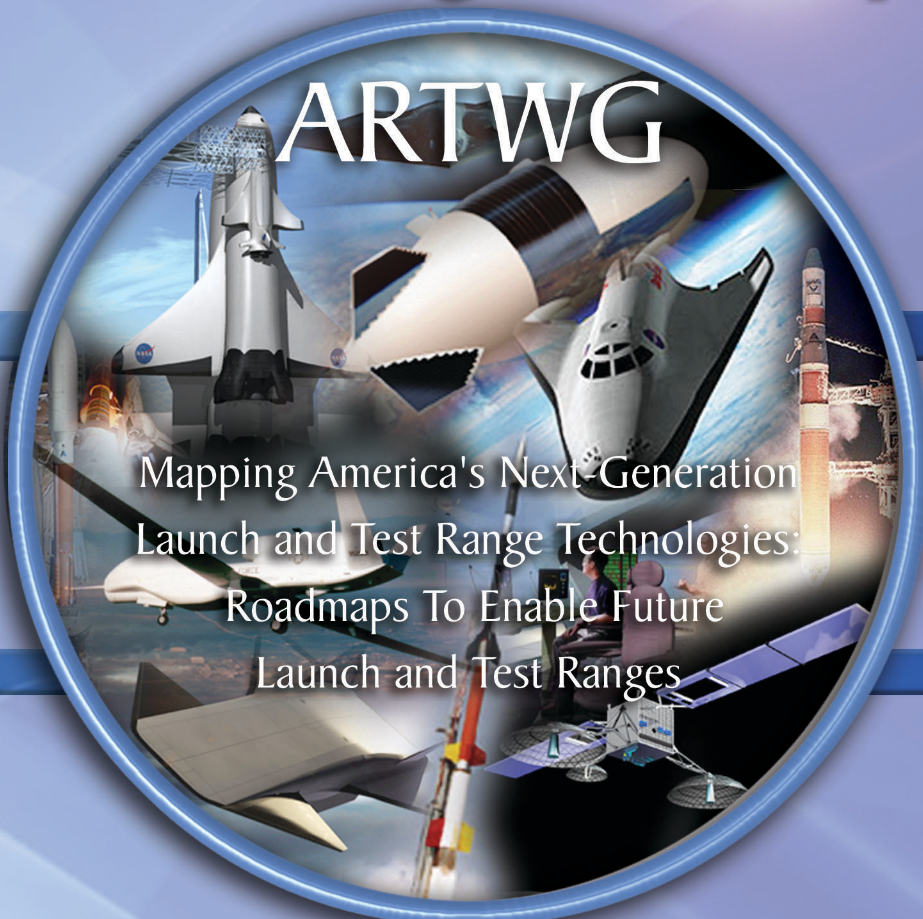
Advanced Range Technologies Working Group



March 2004

Co-Chairs
NASA Kennedy Space Center
Air Force Space Command

U.S. AIR FORCE

Advanced Range Technologies Working Group (ARTWG)

Mapping America's Next-Generation Launch and Test Range Technologies:

Roadmaps To Enable Future Launch and Test Ranges

Co-Chairs: NASA Kennedy Space Center
Air Force Space Command

Foreword

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Advanced Range Technologies Working Group Membership

30th Space Wing
45th Space Wing
ACTA Inc.
Aerospace Corporation
Aerospace Industries Association
Aerospace States Association
Aero-Thermo Technology, Inc.
Aim8 Product Development Inc.
Air Force Research Laboratory
Air Force Space Command
Air Traffic System Requirements Service
Alliant Techsystems Inc.
All Points Logistics, Inc.
Altech Services, Inc.
Analex Corporation
Anteon Corporation
Applied Meteorology Unit
Applied Physics Lab
APT Research
ASRC Aerospace
ATK Tactical Systems
Avmet Applications International
BAE Systems
Boeing
Booz Allen Hamilton
California Space Authority
CMC Electronics
Coleman Aerospace
Command & Control Technologies Corp
Computer Sciences Raytheon
Custom Manufacturing & Engineering, Inc.
Delta Velocity Corporation
Department of Commerce (DOC)
Department of Transportation (DOT)
DFI International
Dynacs Engineering Co.
Dynamac Corp.
Ebertech Electronic Solutions
Edwards Air Force Base
Elgin Air Force Base
ENSCO, Inc.
Federal Aviation Administration
Florida Air National Guard
Florida Space Authority
Harris Corporation
Hernandez Engineering
Honeywell Space Systems
Indyne
Infoware Systems Inc.
Institute for Defense Analysis
Interface and Control Systems
International Consortium for Telemetry Spectrum
ISDR
ITT Industries, Systems Division
Kelley Logistic Support Systems
Kirtland Air Force Base
Kistler Aerospace
Knowledge Based Systems Inc.
KT Engineering
L3 Communications
Le Bas International
LJT and Associates
Lockheed Martin
Loral Space and Communications
Microcosm, Inc.
MITRE
NASA Ames Research Center
NASA Dryden Flight Research Center
NASA Glenn Research Center
NASA Goddard Space Flight Center
NASA Jet Propulsion Laboratory
NASA Johnson Space Center
NASA Kennedy Space Center
NASA Langley Research Center
NASA Marshall Space Flight Center
NASA Stennis Space Center
NASA Wallops Flight Facility
National Coalition of Spaceport States
National Oceanic and Atmospheric Administration
Navair
Naval Ordnance Test Unit (NOTU)
NAWC-WD Pt Mugu
Nebraska Space Grant Consortium
New Mexico State University
Nnorth Consulting
North Carolina A&T State University
Northrop Grumman
Optimal Synthesis, Inc.
Orbital
Peterson Air Force Base

Reagan Test Site
Reliable System Services Corporation
RSO Inc.
RSS Corp.
RTI International
RTS
SAIC
SBC Global
Schafer
Scitor
SGS
Sigmatech
SI International
Southern Marketing
SPACE.com
Spaceflight Meteorology Group
Space Information Labs, Inc.
SRI International
SRS Information Services
Sverdrup Technologies
The Madewell Group
Tinker Air Force Base
Titan Systems
TYBRIN
United Paradyne Corporation
University of Alaska at Anchorage
University of Arizona
University of Central Florida
University of Nebraska Lincoln
University of Oklahoma
U.S. Air Force Headquarters
U.S. Navy
Vandenberg Air Force Base
Veridian
VidNet Systems, Inc.
Virginia Space Flight Authority
Wallops Flight Facility
White Sands Missile Range
Wright-Patterson Air Force Base
Zel Technologies, Inc.
ZHA Inc.

Advanced Range Technologies Working Group (ARTWG) Leadership Team

ARTWG Co-Chairs: **Darin Skelly, NASA Kennedy Space Center, Florida**
Major Debra Fogle, HQ AFSPC/XPX, through May 2003
Major Jennifer Draper, HQ AFSPC/XPXZ

Facilitator: **Timothy Kotnour, Ph.D. Associate Professor, Industrial and Systems Engineering, University of Central Florida, Orlando, Florida**

ARTWG Subgroup Co-Chairs:

Tracking and Surveillance
Lt. Col. Rembert Schofield, 45 RANS/FLANG, Cape Canaveral AFS, Florida
Victor Villhard, Booz Allen Hamilton, Colorado Springs, Colorado

Telemetry
Jim Shaver, NASA Kennedy Space Center, Florida
Dr. Sandra Slivinsky, Air Force Research Lab, Kirtland AFB, New Mexico

Communication Architecture
Erik Denson, NASA Kennedy Space Center, Florida
Karen Barker, Lockheed Martin, Bethesda, Maryland

Range Command and Control Systems
Steve Swichkow, NASA Kennedy Space Center, Florida
Dr. Paul Phister, Air Force Research Lab, Rome, New York

Decision Making Support
Kathy Potter, NASA Kennedy Space Center, Florida
Marti Fallon, Aerospace Corporation, Colorado Springs, Colorado

Planning, Scheduling, and Coordination of Assets
Marty Waldman, 30th Space Wing, Vandenberg AFB, California
Darren Buck, United Space Alliance, Cape Canaveral, Florida, through May 2003
William Nelson, Booz Allen Hamilton, Santa Maria, California

Weather Measurement and Forecasting
John Madura, NASA Kennedy Space Center, Florida
Rick Heuwinkel, FAA/ARS Washington, D.C. through May 2003
Joann Ford, FAA/ARS, Washington, D.C., since May 2003

Additional assistance with development of report:

- **California Space Authority**
- **Booz Allen Hamilton**

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

On February 8, 2000, the White House released a report titled, "The Future Management and Use of the U.S. Space Launch Bases and Ranges." The report recommended "the Air Force and NASA should develop a plan to examine, explore, and proceed with next-generation range technology development and demonstration, with a focused charter to improve safety, increase flexibility and capacity, and lower costs for reusable and expendable launch vehicles." In response to this recommendation, NASA and the United States Air Force (USAF) established the Advanced Range Technologies Working Group (ARTWG).

PURPOSE

The purpose of the ARTWG is to cooperatively develop a national vision through a broad coalition of space transportation industry experts and stakeholders. The ARTWG provides a forum and framework to formulate a strategy and identify enabling technologies needed to achieve that vision. Membership includes NASA Centers/Programs, private industry, current and future spaceport and range customers, operators and developers (including existing and emerging launch services providers), commercial and emerging spaceports, academia, states, the Federal Aviation Administration (FAA), Department of Defense (DoD), and Department of Commerce (DOC). The ARTWG was chartered to:

- Identify space launch and test range technology needs for a broad spectrum of ranges.
- Develop a roadmap (plan) that contains project options for the development and demonstration of range technologies that will meet the needs of the existing and future ranges established by Federal policy or by other U.S. entities.
- Develop plan approaches and options for reaching the next-generation advanced ranges of the future.

The ARTWG focus includes:

- Orbital and suborbital ranges tracking expendable and reusable launch vehicles.
- Government and nongovernment, existing and future ranges.

The ARTWG has subdivided the "Range" into seven technical focus areas, which include:

- Tracking and Surveillance
- Telemetry
- Communication Architecture
- Range Command and Control Systems (RCCS)
- Decision Making Support
- Planning, Scheduling, and Coordination of Assets
- Weather Measurement and Forecasting

The Advanced Spaceport Technologies Working Group (ASTWG) addresses spaceport (ground launch site) technologies and also pulls the Cross-Cutting Architecture Roadmaps that were consistent in many technology focus areas. The ARTWG is coordinating its activities with the ASTWG so that two key areas of the Macro Space Transportation System, Range and Spaceport, are addressed (see Figure ES-1).

Spaceport and range technologies will help enable the transition toward more of the total time, cost, and schedule associated with space transportation being dedicated to flight instead of ground processing.

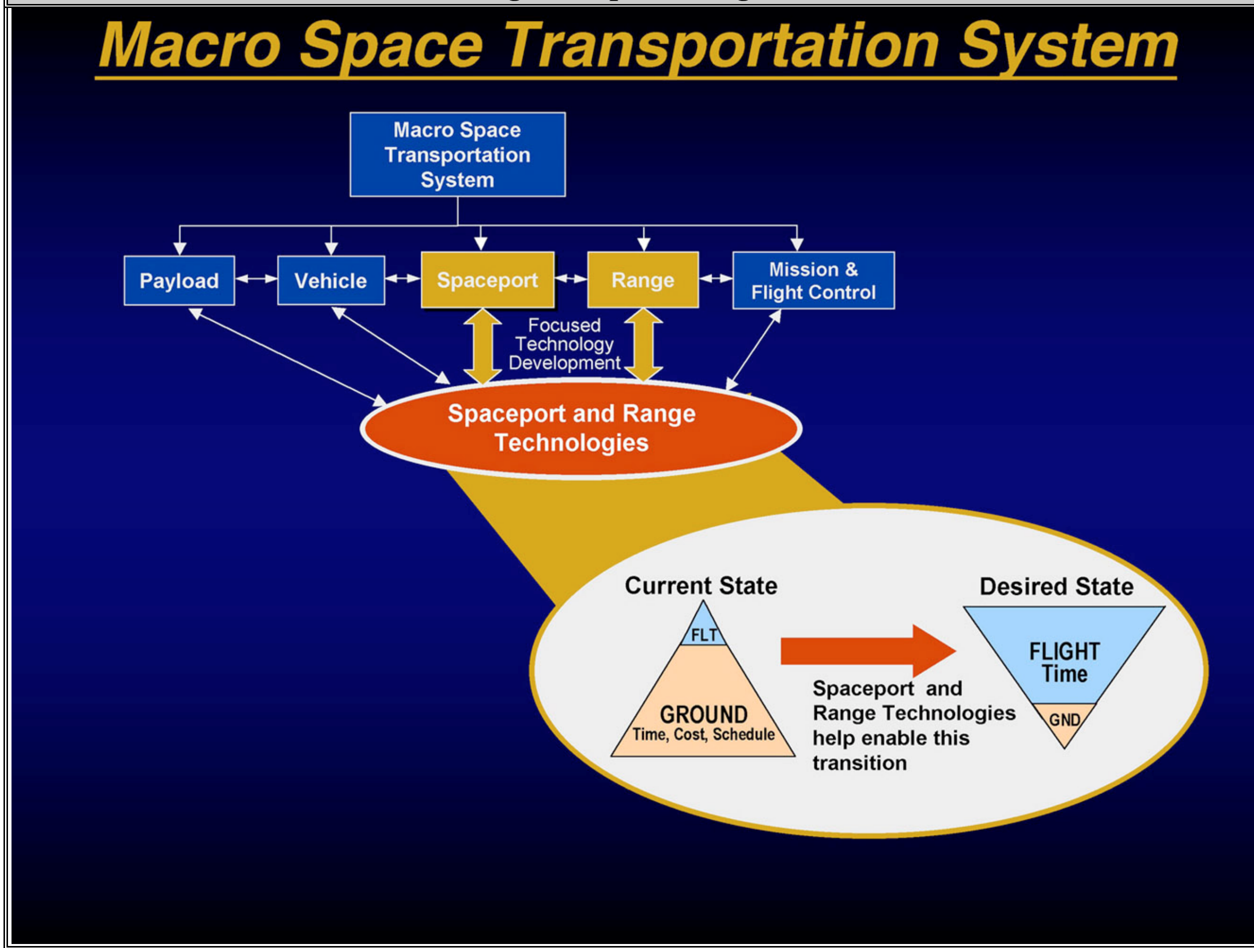

Figure ES-1 Spaceport and Range Elements of the Macro Space Transportation System

SCOPE

Future next-generation range functions will be driven by the needs of various range stakeholders, including spaceport operators; launch vehicle and payload designers, developers, and operators; range administrators; and oversight and regulatory arms of the Federal government. Each stakeholder group has its own set of needs today and for the future. Some of these needs overlap, including the desire for reliable, responsive, and cost-effective range operations. Others are more unique to individual stakeholder groups. For example, DoD is more interested than some of the other stakeholders in the ability to responsively launch and operate spacecraft in orbit, requiring responsive range support as well. Figure ES-2 summarizes the results of the

ARTWG's assessment of the various range stakeholders' current and future needs for range capabilities.

A variety of range stakeholders in several categories has some common and unique needs today and for the future.

Affordable Access to Space

Common Needs: safety, security, resource protection (including physical security, force protection, and information assurance), lower costs, greater flexibility, increased capacity and concurrent operations, shortened flight plan approval, effective data handling and information systems.

Stakeholder Group	Stakeholders	Today's Needs	Future Needs
Spaceports (Customer)	• Federal Spaceports • State Spaceports • Commercial Spaceports • Developing Spaceports	• Flexible, robust, and efficient systems that can support high-flight rates • Shared-use infrastructure that supports concurrent operations • Cost-effective systems • Opportunities to create viable new spaceports • Effective master planning	• Cost-effective • Ability to access a variety of orbits • Effective master planning • Multimode transportation • Effective data handling and information systems

Launch Vehicle Designers, Developers, Providers, and Operators
(Customer)
	• Government
	  • Military
	  • Civil
	  • Other
	• Commercial
		• Responsive and robust range
		• Engineering data during development
		• Reliable and flexible launch dates
		• Effective data handling and information systems
		• Effective regulatory coordination
			• Efficient, cost-effective, responsive, and robust range
			• Evolving regulatory process in space with vehicle developments
			• Less impact to vehicle systems
			• Vehicles with short turnaround time
			• Simplified/standardized system interfaces

Payload Providers and Developers
(Customers)
	• Government
	  • Military
	  • Civil
	  • Other
	• Commercial
	• Nonprofit (e.g., academia)
		• Responsive and robust range
		• Reliable and flexible launch dates
		• Rapid access to space (DoD)
		• Highly reliable vehicles
		• Increased standardization between vehicle and operations
			• Responsive and robust range
			• Large surge launch rate capability
			• International range compatibility
			• Short notice launch and landing world wide
			• Improved coordination

Range Administrators (Owners and operators)	• Military • Civil • Other	• Consistent compliance processes • Increased automation • Low turnaround time between launches • Highly reliable vehicles	• Reduced asset costs • Full integration with FAA ATC, space surveillance network • Interoperability between ranges • Align range to support routine operations or test and evaluation • Global coverage
Federal and State Governments (Funding and oversight)	• U.S. Government • State Governments • Local Governments	• Economic competitiveness • Environmental stewardship • Standardized and simplified Government policies • Workable, effective regulations	• Routine space transportation • Appropriate regulatory processes that meet public safety and commerce needs • International agreement on Range operations

Figure ES-2 U.S. Range Stakeholders' High-Level Needs

Two primary types of missions are likely to require support from space launch and test ranges in the future. They are:

- Space Launch and Recovery Operations – Including, for example, expendable launch vehicle (ELV), Space Shuttle, and reusable launch vehicle (RLV) launch and recovery operations, including suborbital RLVs and entrepreneurial systems, for a wide variety of national security, civil, and commercial missions, and launches and recovery operations involving the Orbital Space Plane (OSP) and Next-Generation Launch Technology (NGLT) being developed under NASA's Space Launch Initiative (SLI), part of its Integrated Space Transportation Plan (ISTP). In the far term, it is envisioned that suborbital RLVs (SRLV) will emerge and also "drive" the space-launch industry market.

- Test and Evaluation (T&E) Mission – Including, for example, aeronautical flight testing of civil and military aircraft and flight systems, various types of guided missiles, and unmanned aerial vehicles (UAVs) with a variety of possible applications; intercontinental ballistic missile (ICBM) and submarine-launched ballistic missile (SLBM) T&E missions; orbital and suborbital flight demonstrations for DARPA's operationally responsive FALCON Program, Ballistic Missile Defense Systems (BMDS) T&E, and flight testing of hypersonic missiles, propulsion systems, and vehicles as part of the National Aerospace Initiative (NAI) - a cooperative effort across DoD and NASA. Although this mission is not the primary focus of the ARTWG, the technologies being identified are synergistic with the advancements needed in this community (see Figure ES-3).

Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Far-Term (FY 2016 - 2028)
		

Figure ES-3 Examples of Future Space Launch Vehicles Requiring Range Support

While space launch and T&E missions are challenging for the space launch ranges to support, the most "stressing" technical challenges will be for future SRLVs, and the currently planned T&E activities associated with the planned flight testing of ballistic missile defense systems involve multiple high-speed targets and interceptors being launched from multiple locations, including ships and aircraft, at widely dispersed geographic locations.

APPROACH

Recognizing the ARTWG as an interagency program formulation effort that involved a diverse set of stakeholders, ARTWG followed a three-pronged approach to developing the ARTWG Technology Plan (see Figure ES-4). The three efforts focused on:

1. Build and follow a Strategic Program

2. Build the ARTWG Technology Plan

3. Build the ARTWG Community

ARTWG undertook an interagency program formulation effort with a diverse set of stakeholders by following a three-pronged approach to developing Technology Roadmaps.

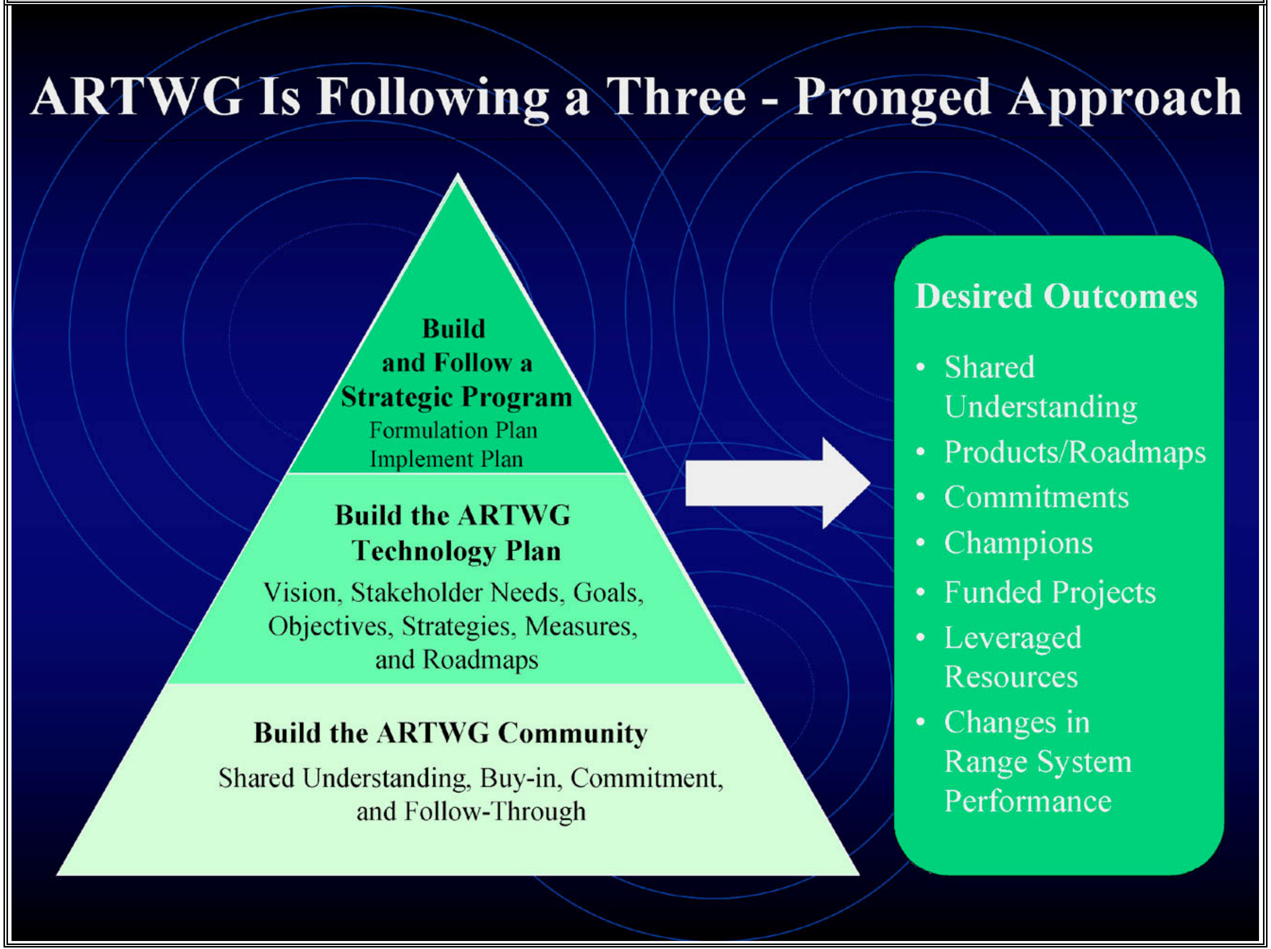

Figure ES-4 ARTWG's Three-Pronged Approach

To accomplish the scope of the ARTWG charter, ARTWG developed an integrated approach to ensure all interested stakeholders would be able to participate. To build a broad level of involvement, the ARTWG undertook the following actions:

- Implemented a shared leadership structure across agencies and organizations.
- Invited participation within the working groups.
- Conducted open meetings, conferences, and workshops.

The ARTWG roadmaps and recommendations will be reviewed by senior Government representatives, including:

- Senior Steering Group - Representatives from NASA, FAA, Office of Secretary of Defense (OSD), and USAF to provide guidance to the Executive Steering Committee and the ARTWG Leadership Team. Members will be appointed by NASA and the USAF.

- Executive Steering Committee - Senior Representatives from Federal organizations, such as NASA, USAF, FAA, OSD, and others as appointed to provide senior agency guidance and recommendations.

It is envisioned that the products of the ARTWG will become the national roadmaps for the development of future next-generation space launch and test ranges. All ARTWG efforts were focused on first defining the vision for future range capabilities, then establishing goals and objectives for each function and subfunction within each of the seven technical focus areas. Next, each subgroup outlined a series of technical challenges and approaches to address each challenge. The roadmaps that resulted from the process of defining goals (G), objectives (O), technical challenges (TCH) and approaches (A) are referred to as GOTCHA charts.

VISION FOR IDEAL FUTURE SPACE LAUNCH AND TEST RANGES

Over the past 25 years, a variety of studies have assessed the advantages of various alternative range architectures and approaches. Most recently, the Extended Range Concept Definition Study - sponsored by the California Space Authority and conducted between September 2001 and September 2002 by Booz Allen Hamilton under contract with DoD's Information Assurance Technology Analysis Center - built on this body of range-related studies. It described and evaluated various options and recommended a next-generation space launch and test range based on evaluation criteria established through interaction with range stakeholders. The ARTWG adopted the elements of this study in the course of defining its vision for the future.

A primarily space-centric range supplemented by mobile assets would improve the adaptability and flexibility of future ranges in terms of their ability to accommodate higher- or lower-than-projected workload, provide expanded geographic coverage to a global scale, and provide the ability to increase capacity by using mobile assets for supplemental coverage where and when needed (Figure ES-5). By leveraging synergistic technologies and approaches and by sharing use of systems, such a future range could be less expensive to operate and maintain.

A primarily space-centric range supplemented by mobile range assets would improve adaptability, flexibility, and geographic coverage while providing capacity as needed.

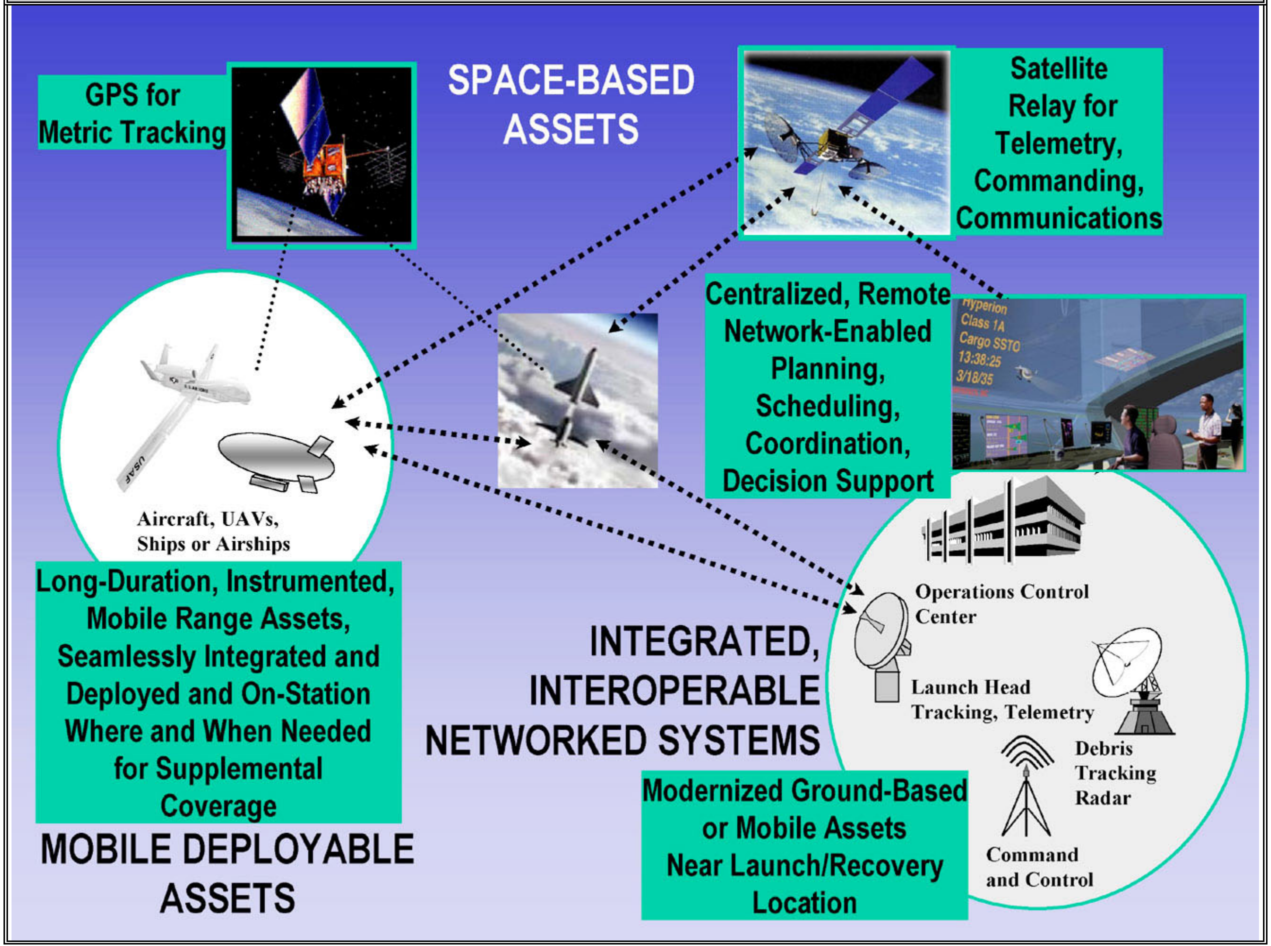

Figure ES-5 Vision for Future Global Launch and Test Range Architecture

Such a future range would use a global positioning system (GPS) for tracking data and communication satellites for relaying telemetry and commands between flight vehicles and range assets, as well as for communications between and among range control centers and range assets. The vision would be to maintain a robust, two-way data link with flight vehicles for both telemetry and commanding. Such a future range would also incorporate modernized ground-based or mobile range assets to provide up-range tracking of debris and telemetry and commanding capabilities required to meet safety standards without the time delay associated with using satellites. Broadband relay satellites would be used as the primary telemetry and commanding capability for down-range operations requiring hemisphere- or global-scale range coverage, where the time delay can be accommodated without adversely impacting the safety of range-supported operations. Mobile range assets would be used to provide additional flexibility to supplement range coverage and capabilities in cases when specific missions require particular range support functions that could not be met by satellites alone.

Developing such a future range architecture with both space-based and mobile range assets would improve adaptability, flexibility, and geographic coverage of range capabilities along with expanded capacity as needed to meet projected missions while enabling incremental development and technology demonstrations at relatively low cost and risk.

ADVANTAGES OF THE FUTURE RANGE VISION

The ARTWG's vision of the ideal range for the far-term future (i.e., 25 years hence) would provide substantial advantages over today's ground-based, fixed-location range architectures in terms of the following desirable characteristics:

a. Reliable, available, operable, and maintainable

b. Adaptable to fit the mission

c. Flexibility/capacity

d. Integrated with other systems

e. Economical

f. Integrated range system

g. Customer friendly

CAPABILITY AND TECHNOLOGY ROADMAPS

The purpose of the ARTWG is to define a national technology strategy to enable development of future space launch and test range capabilities relying primarily on space-based assets, supplemented by mobile range assets (e.g., UAV, high-altitude airship [HAA]) as needed, to meet future mission needs. Each ARTWG subgroup developed both a capability roadmap to establish performance goals and objectives over time and a technology roadmap. Figure ES-6 summarizes the top-level goals for range system capabilities over time.

ARTWG developed a top-level summary of the performance goals over time for future ranges.

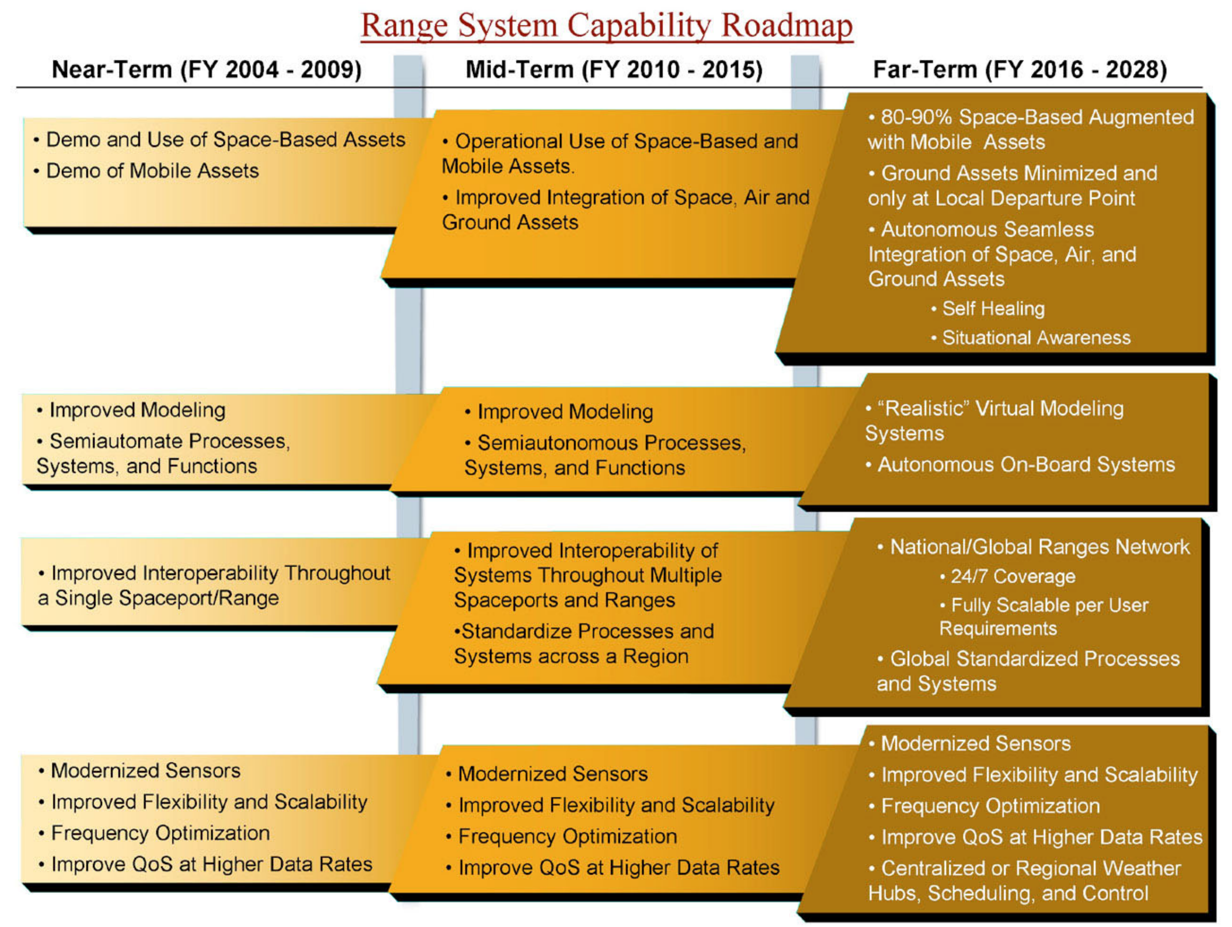

Figure ES-6 Range Vision: System Capability Goals Over Time

For the near-term, the primary focus is on demonstrating the utility and beginning some operational use of existing space-based (e.g., GPS, Tracking and Data Relay Satellite System [TDRSS], etc.) and mobile (i.e., UAV and HAA) assets as range instrumentation platforms. For the mid-term, the focus shifts to more integrated operational use of space-based and mobile-range assets. For the far-term, the goal is to have 80 to 90 percent of range systems on space-based platforms that can be seamlessly augmented when and where needed, with mobile or deployable assets, and modernized ground assets at departure and recovery locations.

Another major development theme is to continue improving modeling, simulations, and database systems to enable semiautomation of processes, systems, and functions through the near-term so they can evolve to semiautonomous capabilities in the mid-term. The far-term goal is to use realistic virtual modeling with intelligent systems and optimized use of autonomous systems for various functions, including onboard flight vehicle systems (if desired) and schedule deconfliction.

A third major development theme is to improve standardization, interoperability, and integration of systems throughout a single spaceport and range that is retrofitted into the National Airspace System (NAS) for the near-term, across multiple spaceports and ranges and integrated into the NAS for the mid-term, and fully integrated across a global range network for the far-term.

Finally, several technical areas of range performance were identified for continuous improvement, including modernizing sensors, optimizing the use of frequency spectrum, and improving quality of voice/video/data communication services at higher data rates.

The ARTWG subgroups used this top-level description of the overall capability and performance goals when describing how the seven technical focus area capabilities should evolve over time.

SUBGROUP CAPABILITY AND TECHNOLOGY ROADMAPS

These products were developed as a result of intensive effort by each subgroup. Each subgroup consisted of subject matter experts from across the country, working together on an ad hoc and voluntary basis, under the direction of the subgroup co-chairs and the ARTWG leadership. They are the product of facilitated brainstorming over the course of several months, review by technical experts, and a facilitated miniretreat for each subgroup to capture the results of these brainstorming activities in a consistent format. The ARTWG leadership team addressed the areas of overlap among the technology areas identified by the subgroups and identified cross-cutting capabilities and technical approaches.

The ARTWG team recognizes that these products can and should be further refined to address inadvertent omissions and developments in current and new technologies being pursued in various Government, commercial, academic, and international environments. It is therefore the intent of the ARTWG to continue pursuing an orderly process over time to evolve and refine these products and produce future updates of the capability and technology roadmaps presented in this section. See Figures ES-7 through ES-22.

TRACKING AND SURVEILLANCE

ARTWG envisions automated surveillance capabilities, GPS for metric tracking, and modernized sensors for fixed, deployable, and space-based platforms.

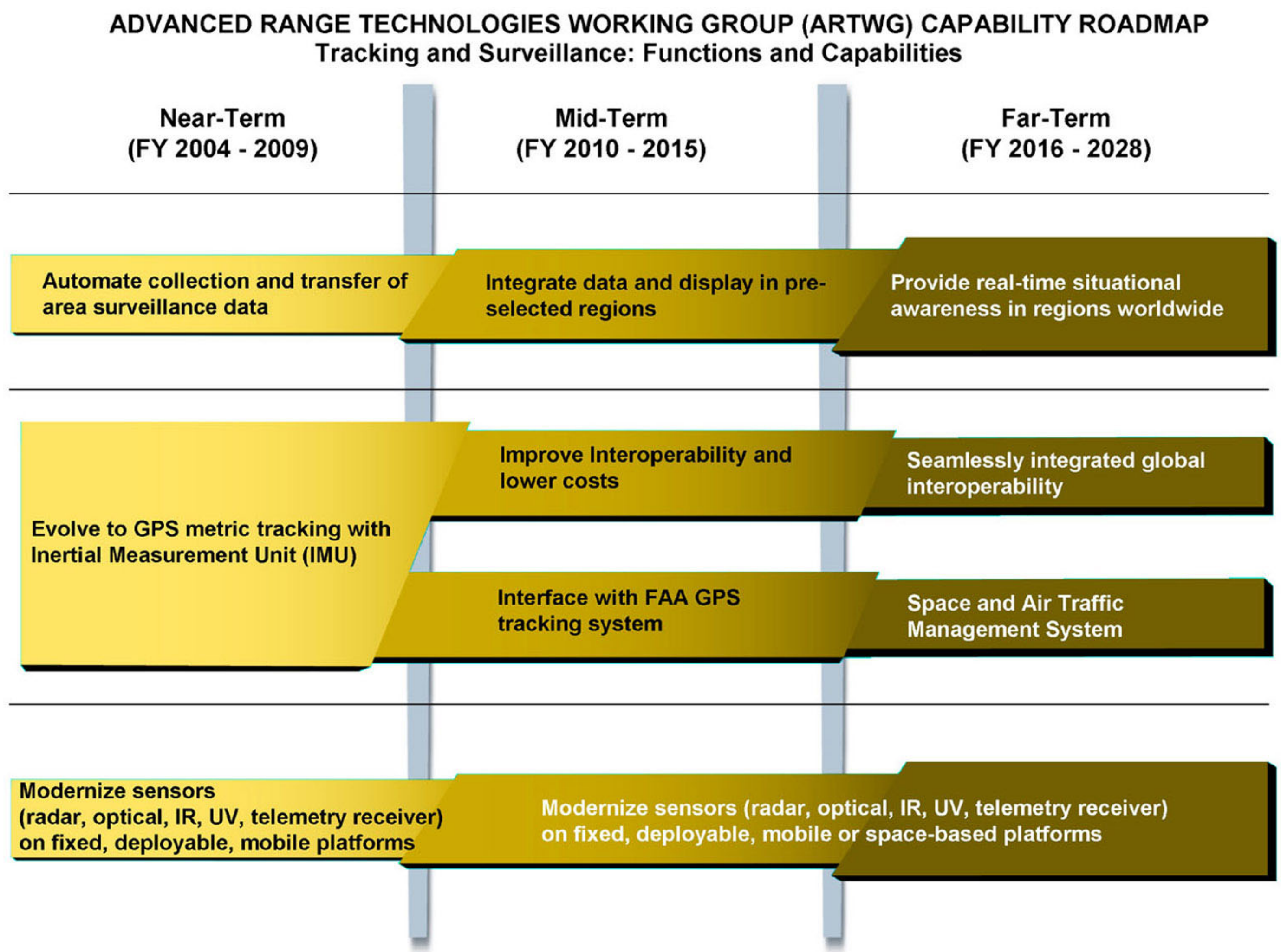

Figure ES-7 Capability Goals Over Time: Tracking and Surveillance

Space-based and mobile platforms, GPS systems, instruments for passive detection in multiple spectral bands, and improved signal processing for error correction and object recognition.

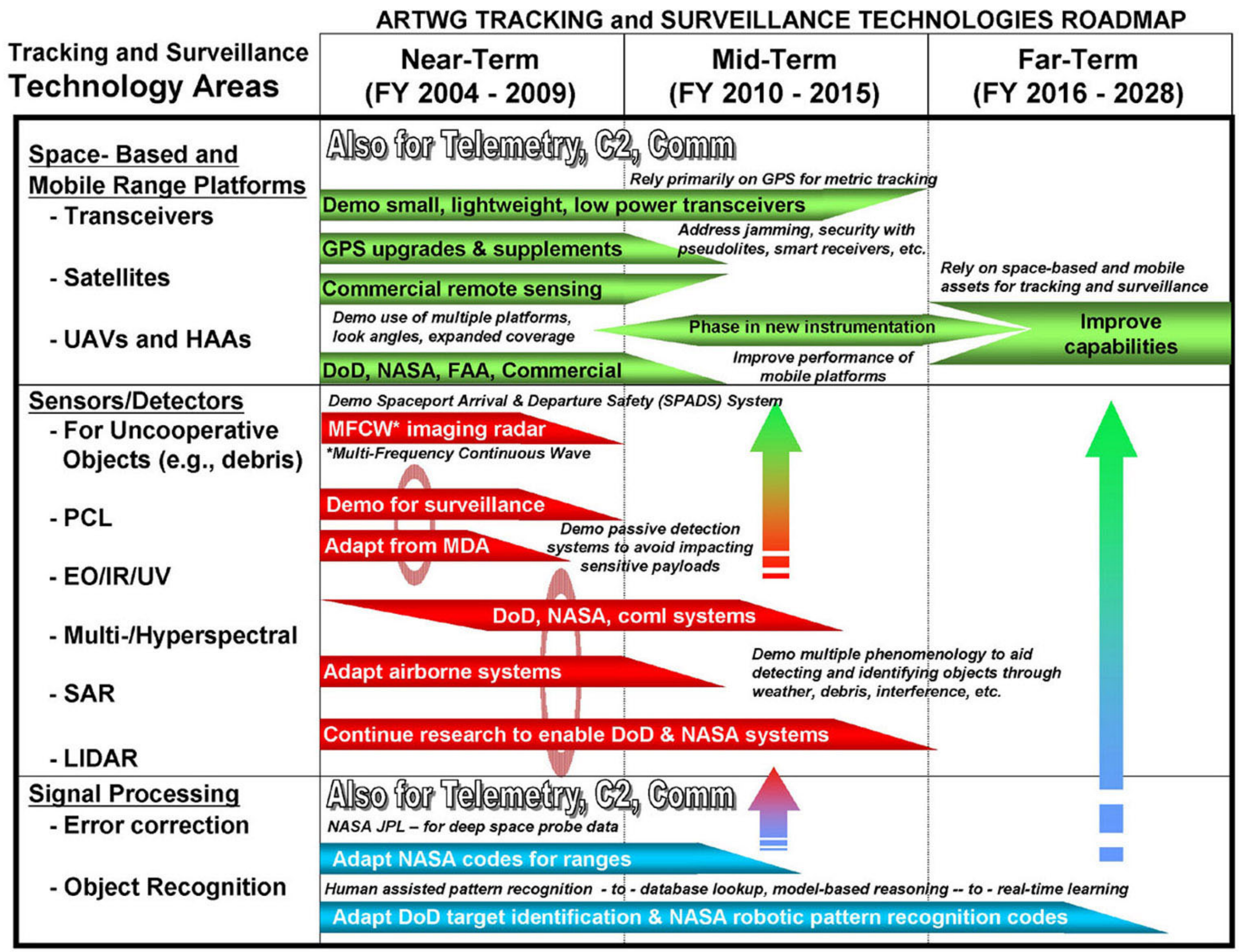

Figure ES-8 Technology Roadmap for Tracking and Surveillance

TELEMETRY

ARTWG envisions satellites and deployable mobile platforms for acquiring and relaying telemetry, eventually combining telemetry and command into one robust two-way link.

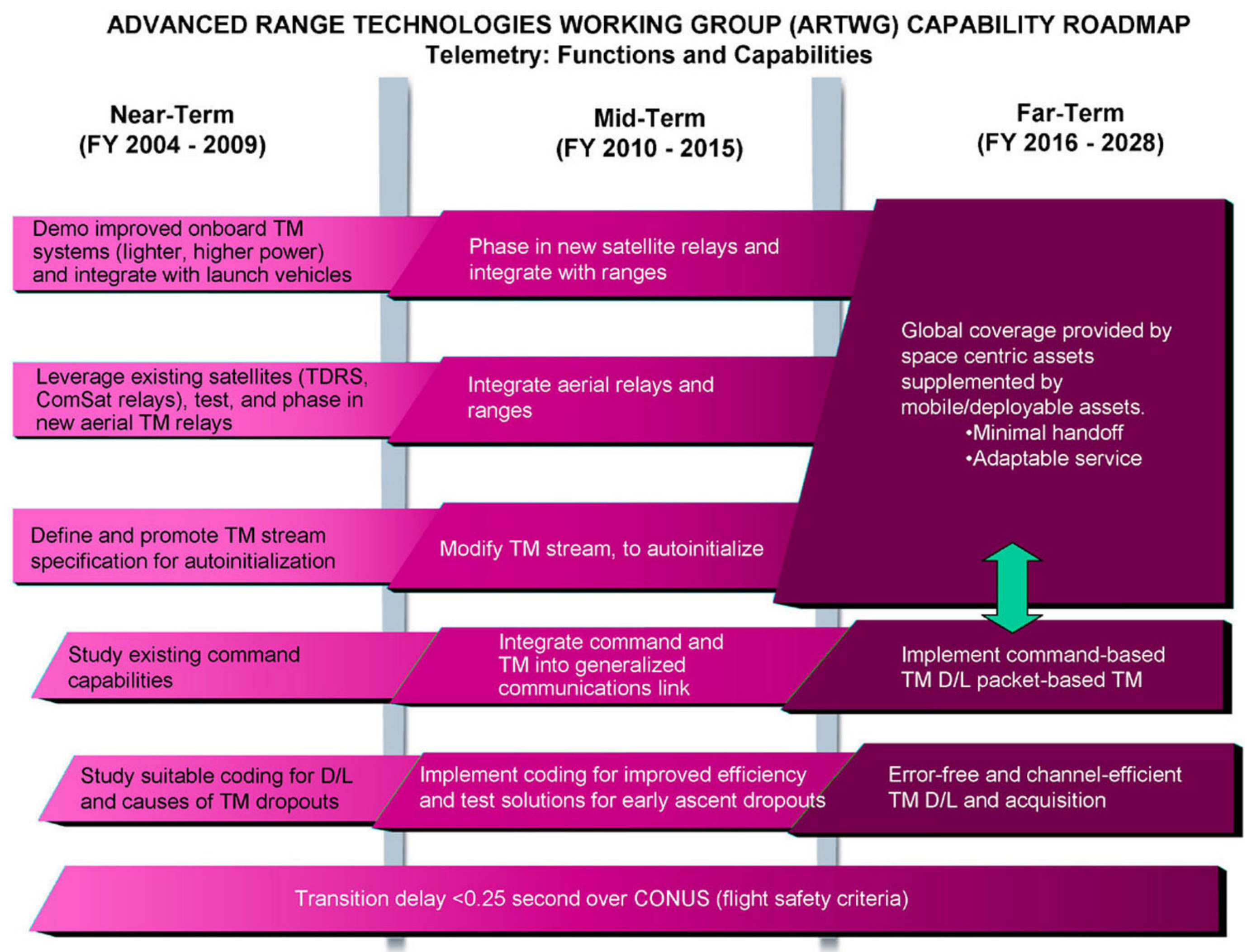

Figure ES-9 Capability Goals Over Time: Telemetry

Space-based and mobile platforms, signal processing, alternate uses of frequency spectrum, antenna technologies, optical and magnetic storage media, and advanced data handling.

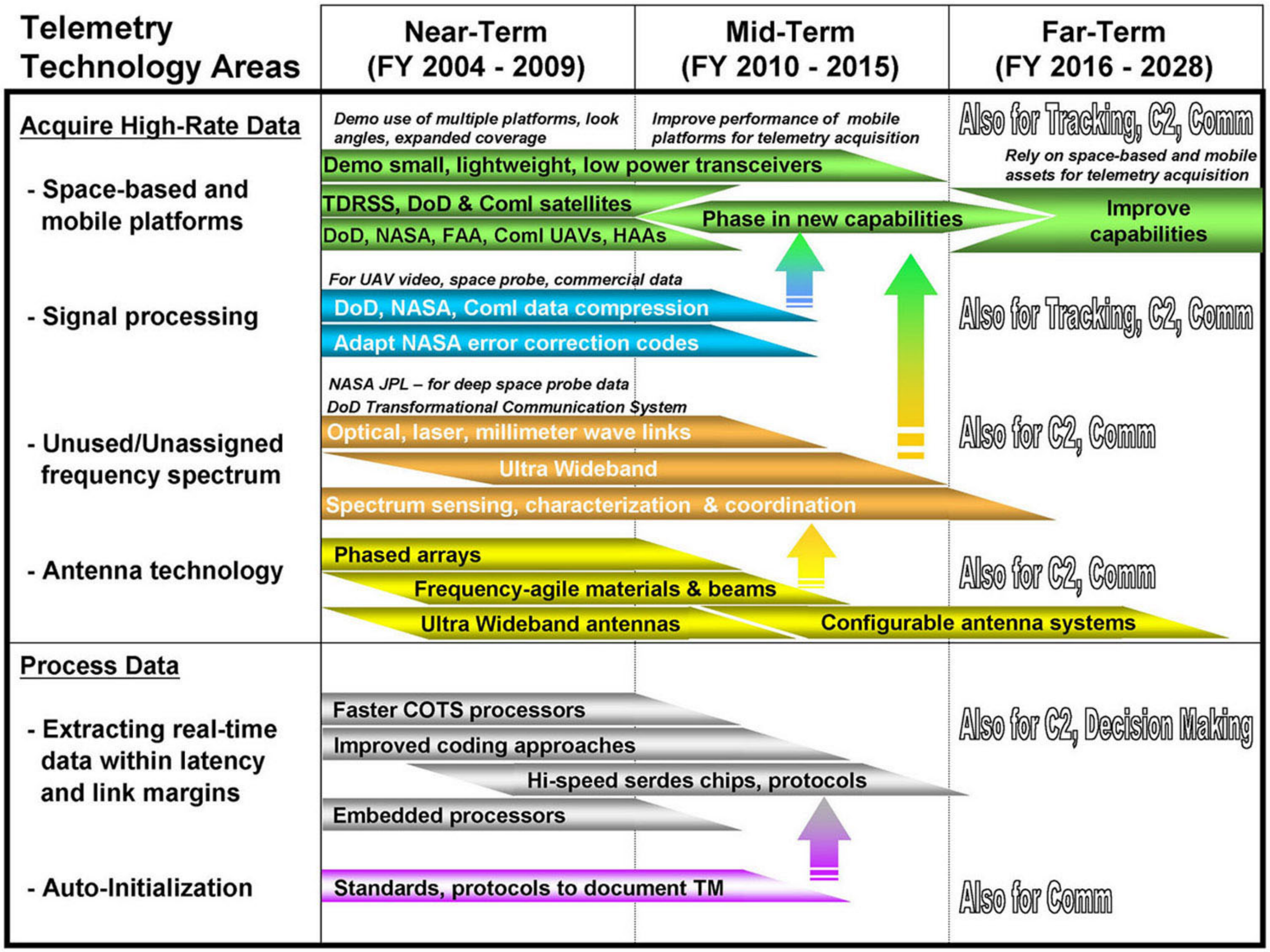

Figure ES-10 Technology Roadmap for Telemetry

COMMUNICATION ARCHITECTURE

ARTWG envisions global network interconnectivity with voice, video, and data distribution through high speed ground networks, satellites, and mobile range assets.

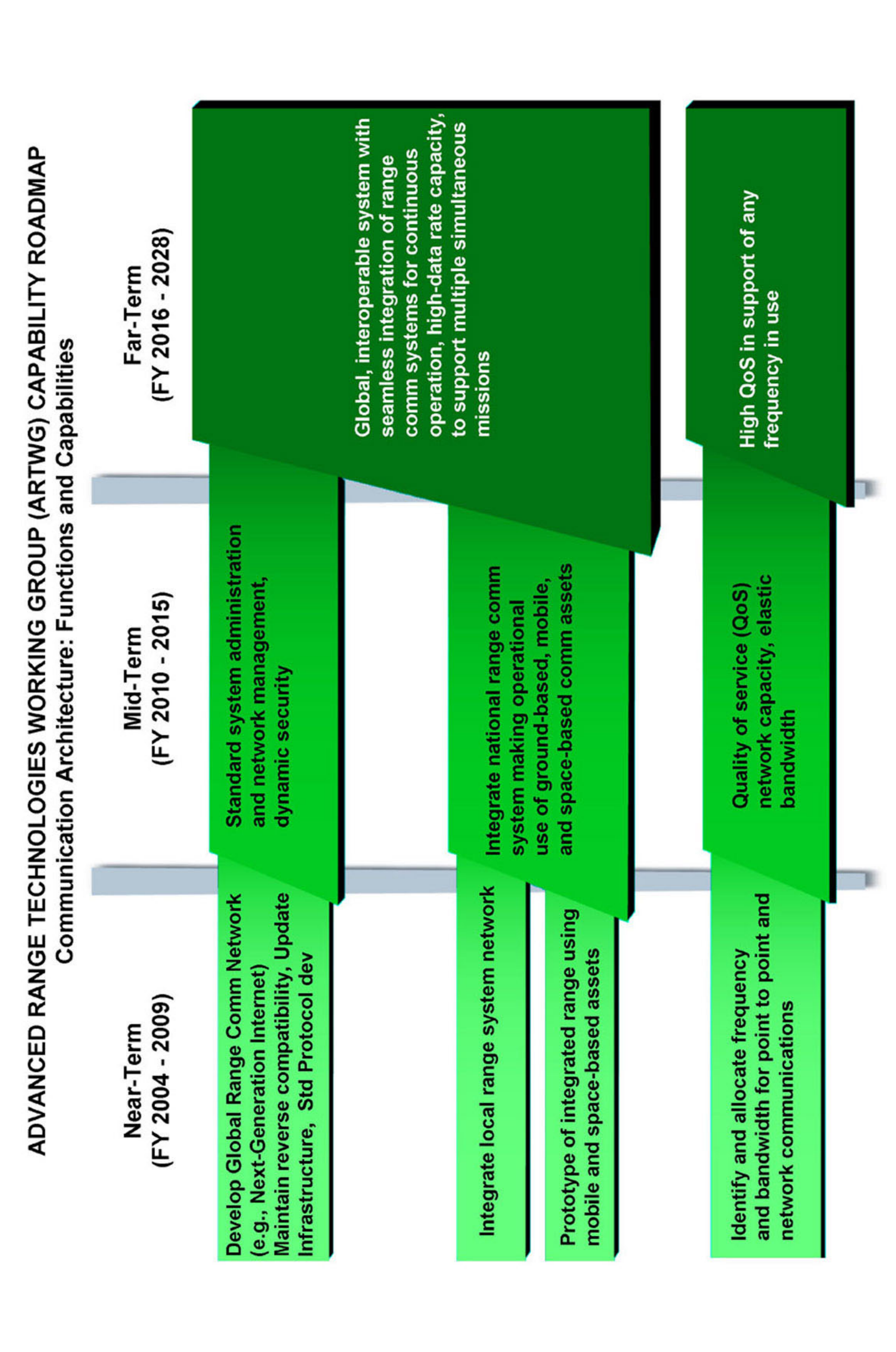

Figure ES-11 Capability Goals Over Time: Communication Architecture

Space-based and mobile platforms, ground networks, signal processing, alternative use of frequency spectrum, antenna technologies, storage media, and advanced data handling.

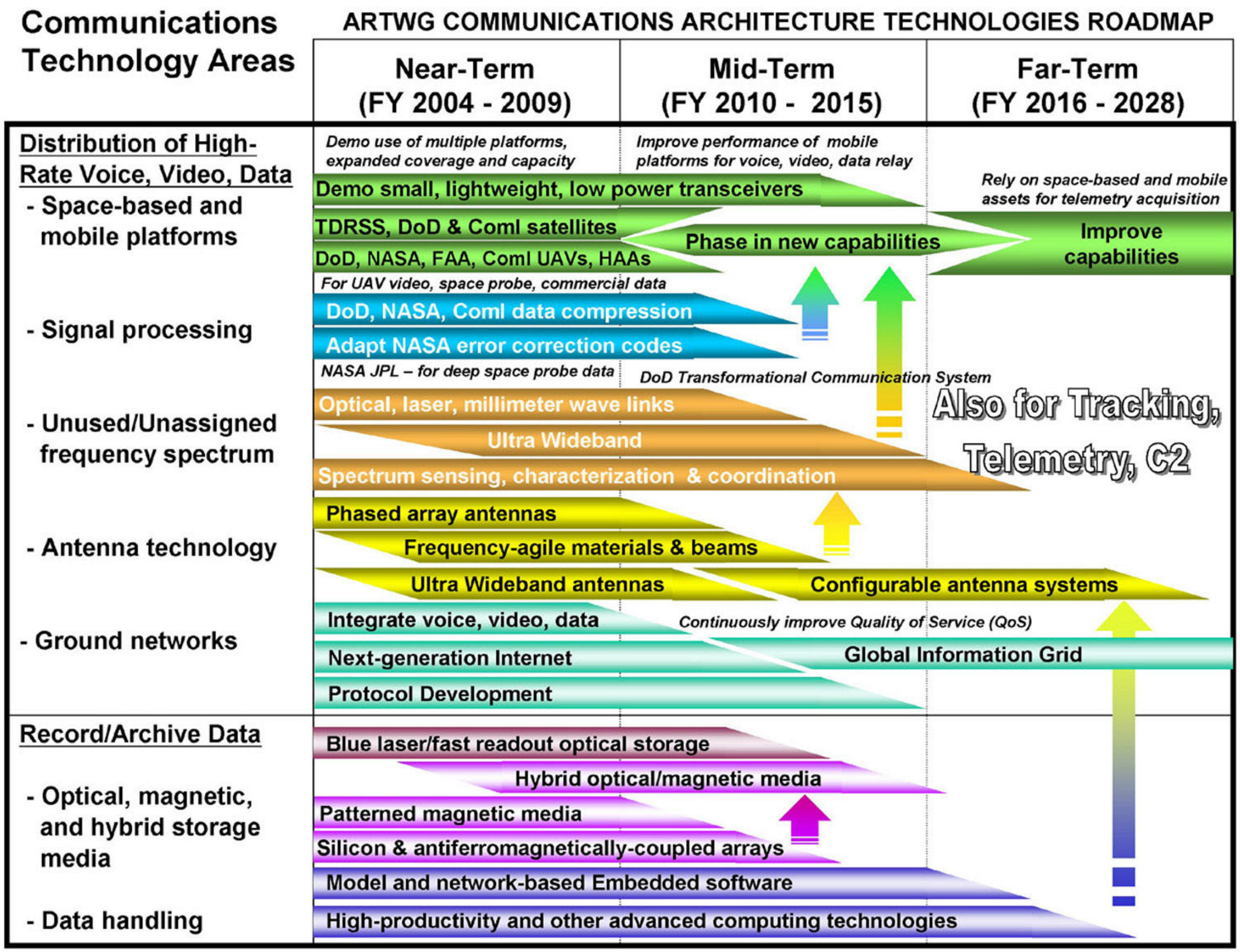

Figure ES-12 Technology Roadmap for Communication Architecture

RANGE COMMAND AND CONTROL SYSTEMS

ARTWG envisions autonomous knowledge-based data fusion, a robust self-organizing network, providing increasingly interoperable, responsive, and flexible range and flight safety support for global operations.

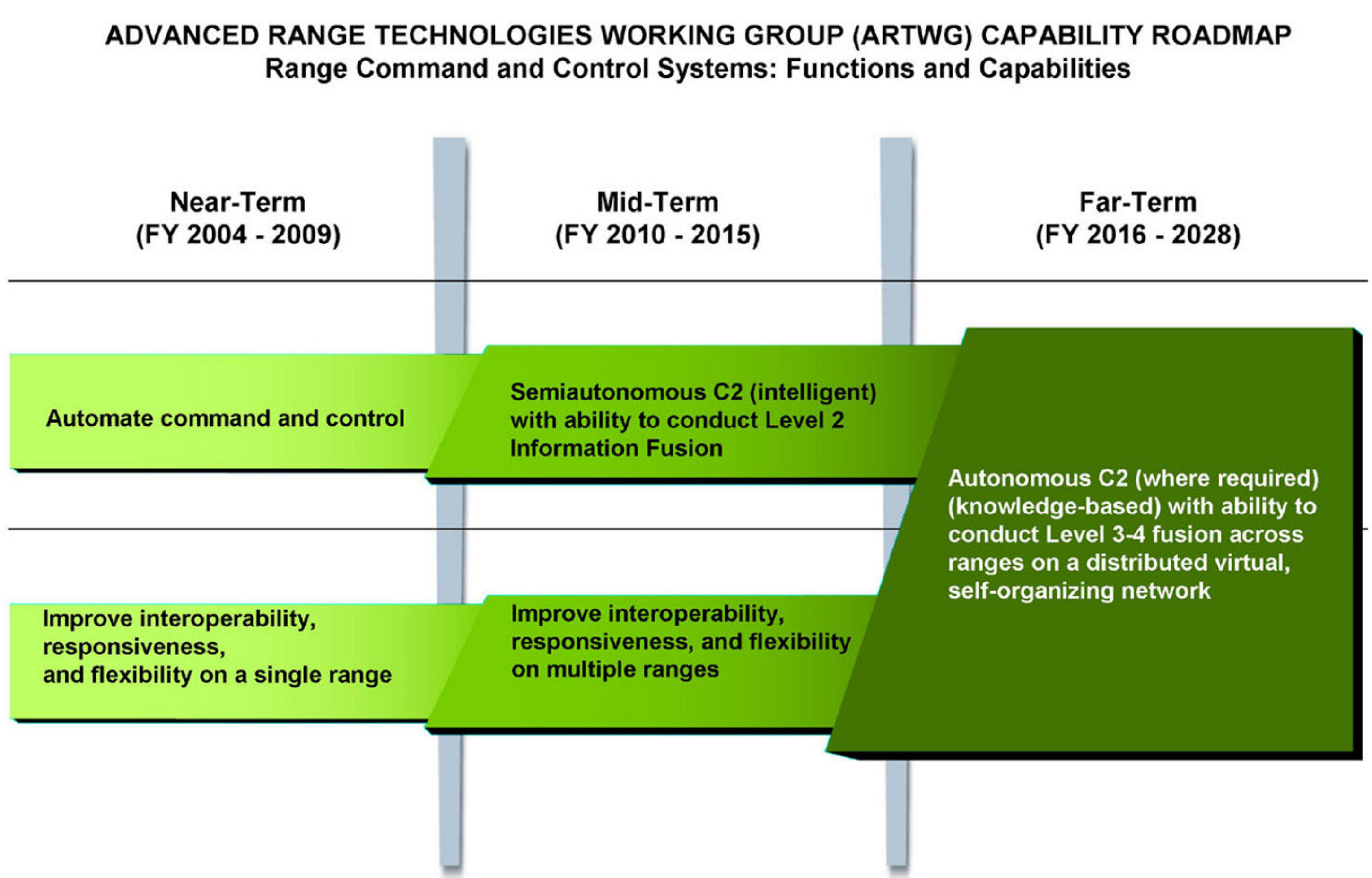

Figure ES-13 Capability Goals Over Time: Range Command and Control

Monitoring range assets, automating reconfiguration capabilities, and executing commands through a robust two-way data link shared with the vehicle telemetry link.

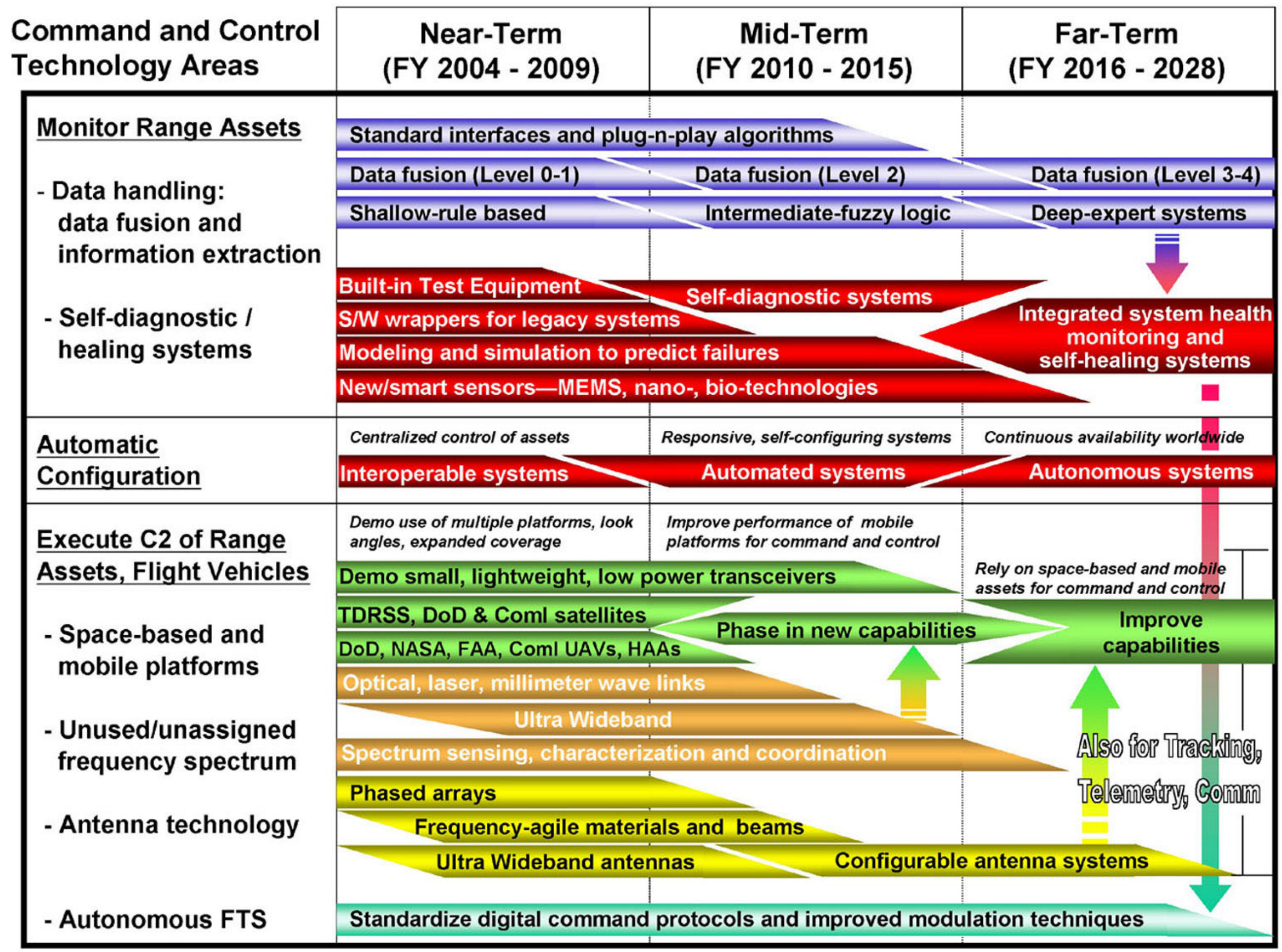

Figure ES-14 Technology Roadmap for Range Command and Control

DECISION MAKING SUPPORT

ARTWG envisions increased standardization in modeling and simulation, collision avoidance, and sophistication of 2-D and 3-D immersion-type displays.

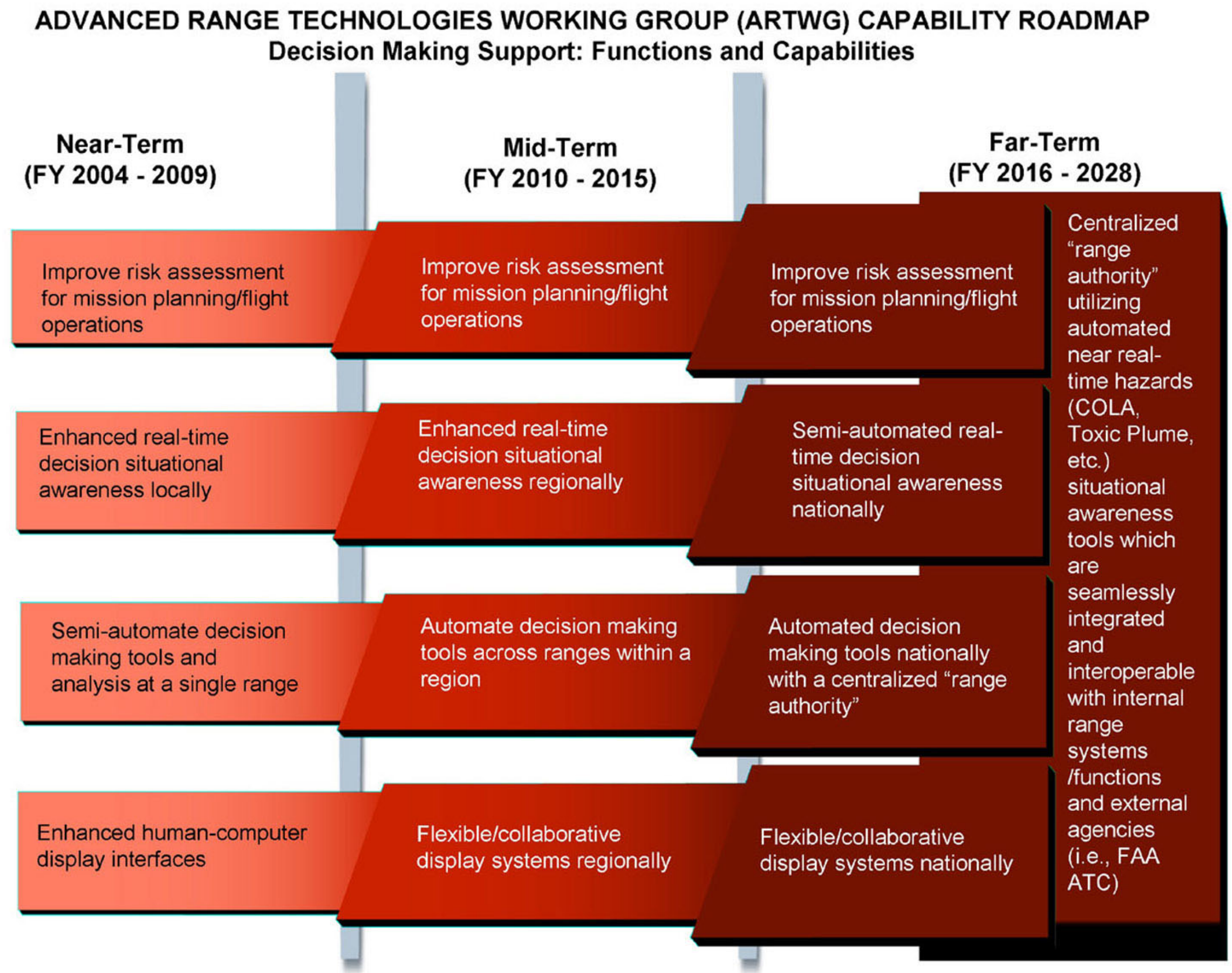

Figure ES-15 Capability Goals Over Time: Decision Making Support

Higher fidelity modeling and simulation based on enhanced data fusion and extraction capabilities, better integration with FAA space and air traffic management systems, and improved display capabilities.

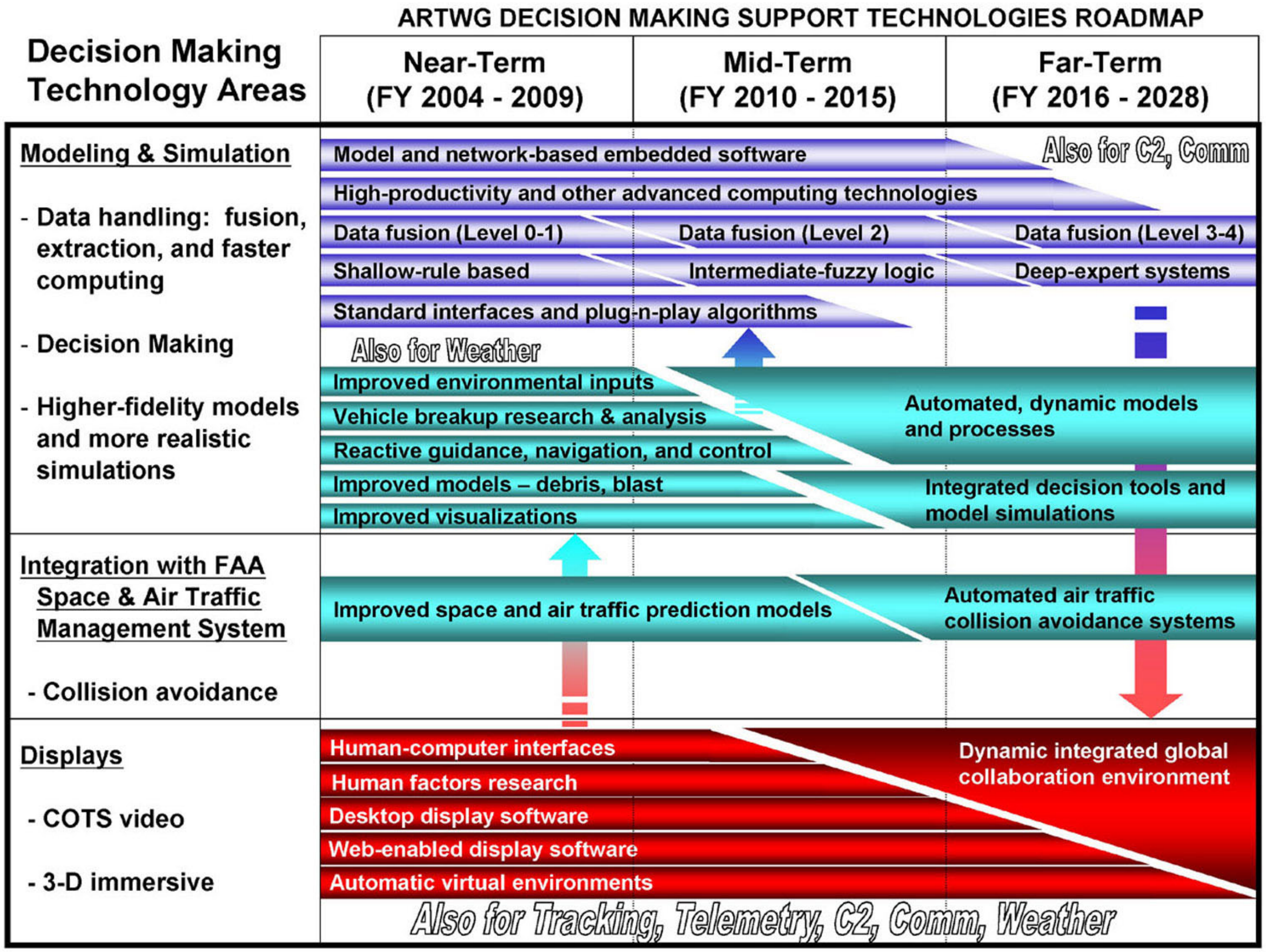

Figure ES-16 Technology Roadmap for Decision Making Support

PLANNING, SCHEDULING, AND COORDINATION OF ASSETS (PSCA)

ARTWG envisions increased automation and centrally addressing range planning, scheduling, and coordination of assets activities on a broader scale.

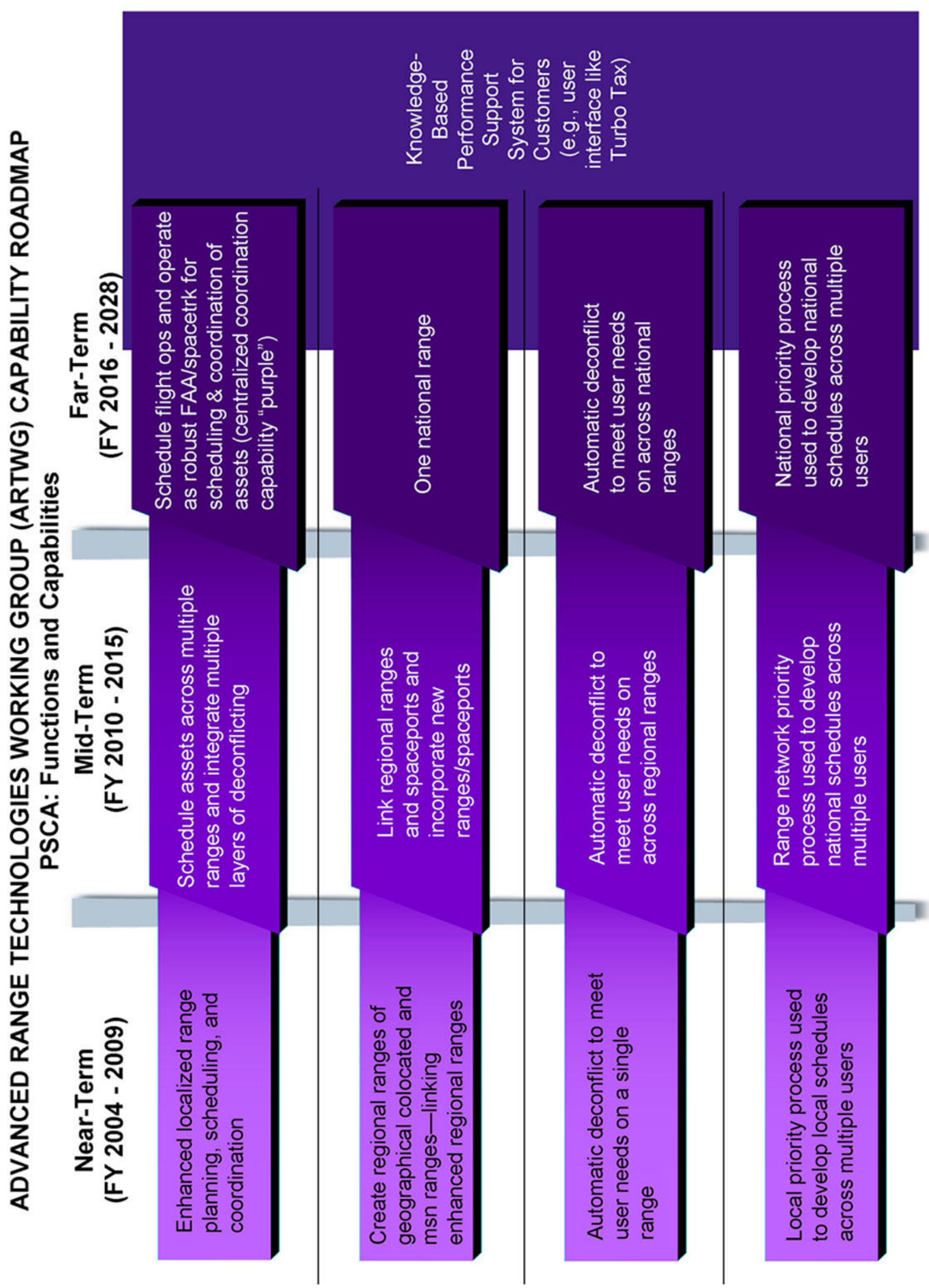

Figure ES-17 Capability Goals Over Time: Planning, Scheduling, and Coordination of Assets

Integrated software tools to evolve from rule-based to knowledge-based expert systems and database systems to enable autonomous scheduling and deconfliction.

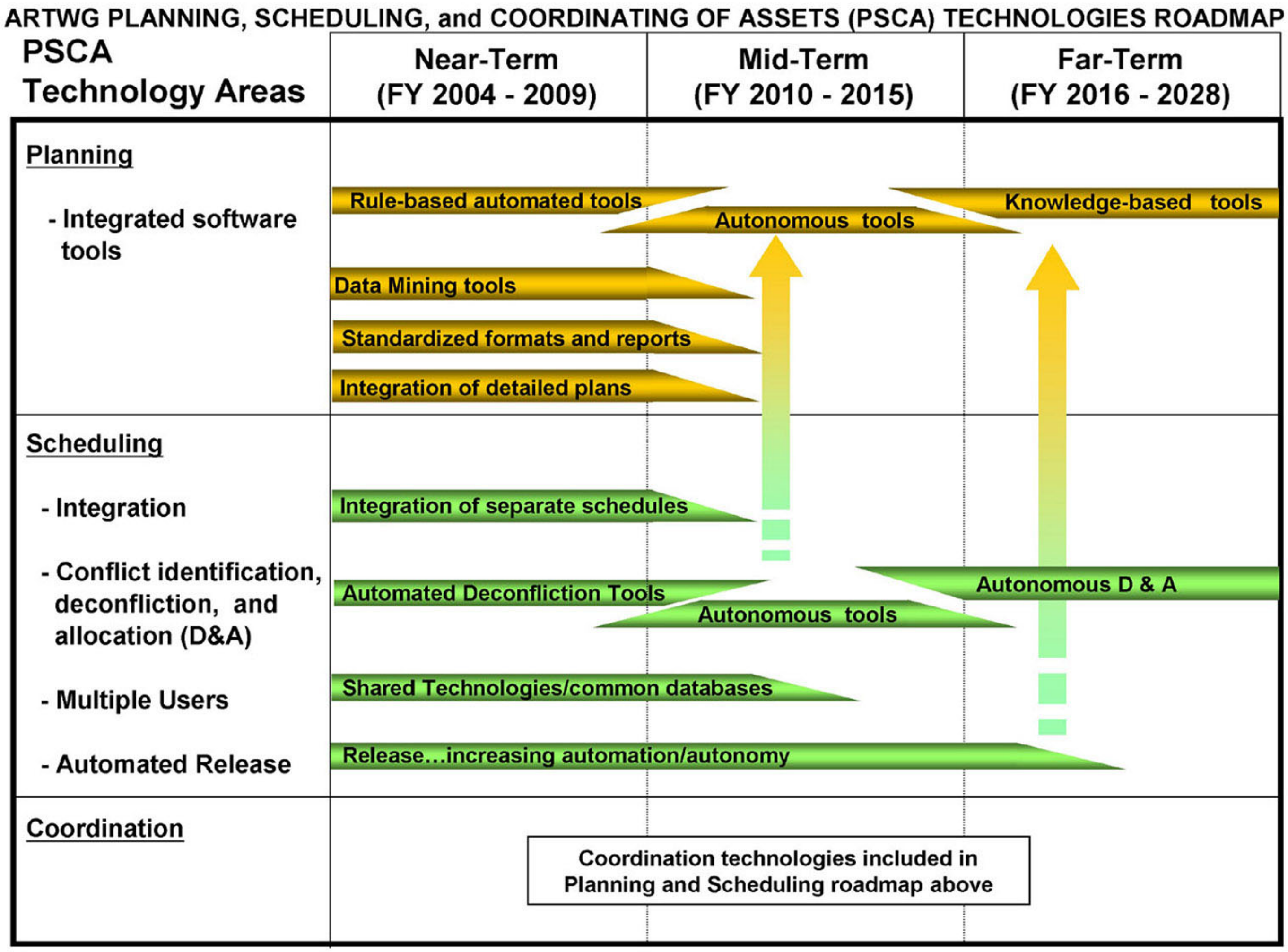

Figure ES-18 Technology Roadmap for Planning, Scheduling, and Coordination of Assets

WEATHER MEASUREMENT AND FORECASTING

ARTWG envisions capabilities in Weather Systems evolving over time toward centralized hubs for forecasting and technology transition, based on improvement of sensors and models.

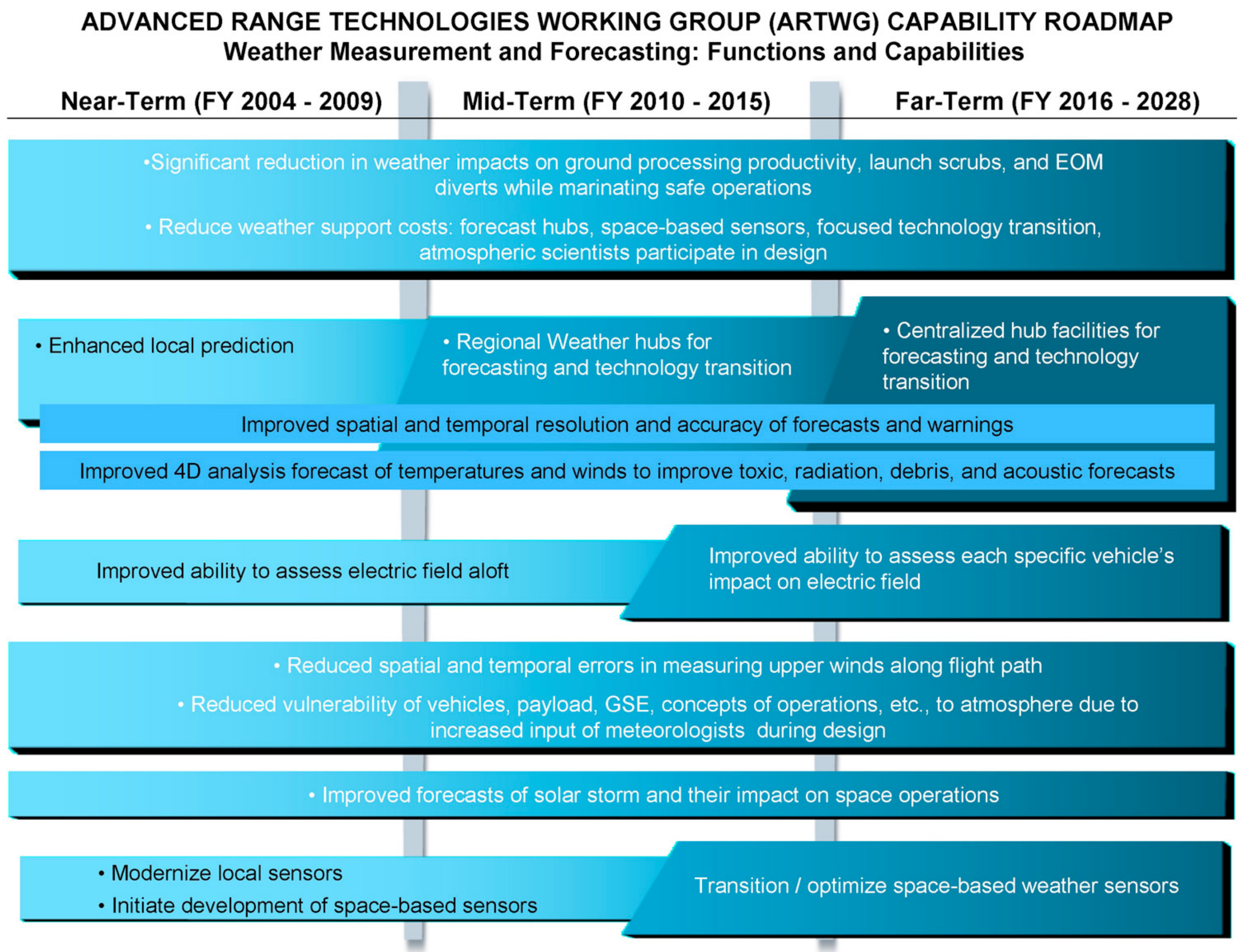

Figure ES-19 Capability Goals Over Time: Weather Measurement and Forecasting

Better sensors, models, and data fusion, communications, flexible lightning and upper level wind launch commit criteria, better use of tools and expertise to develop safer vehicles, better mesosphere and space models.

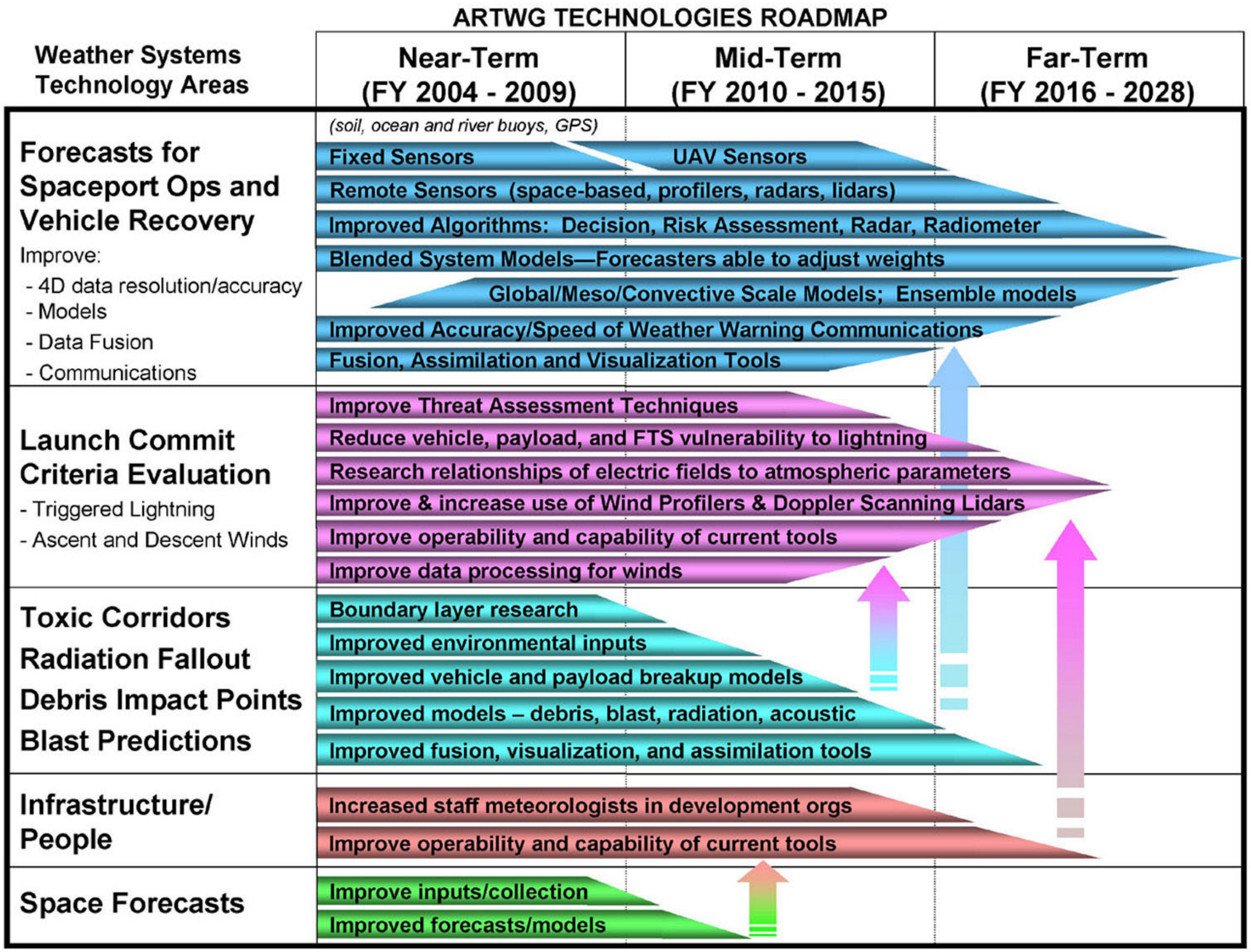

Figure ES-20 Technology Roadmap for Weather Measurement and Forecasting

CROSS-CUTTING ARCHITECTURE

ARTWG envisions commonality among the various subgroups, self-healing networks enhancing the delivery of services within the subgroups, autonomous control and interactive simulation and testing for all operators.

ADVANCED RANGE TECHNOLOGIES WORKING GROUP (ARTWG) CAPABILITY ROADMAP
Cross-Cutting Architecture: Functions and Capabilities

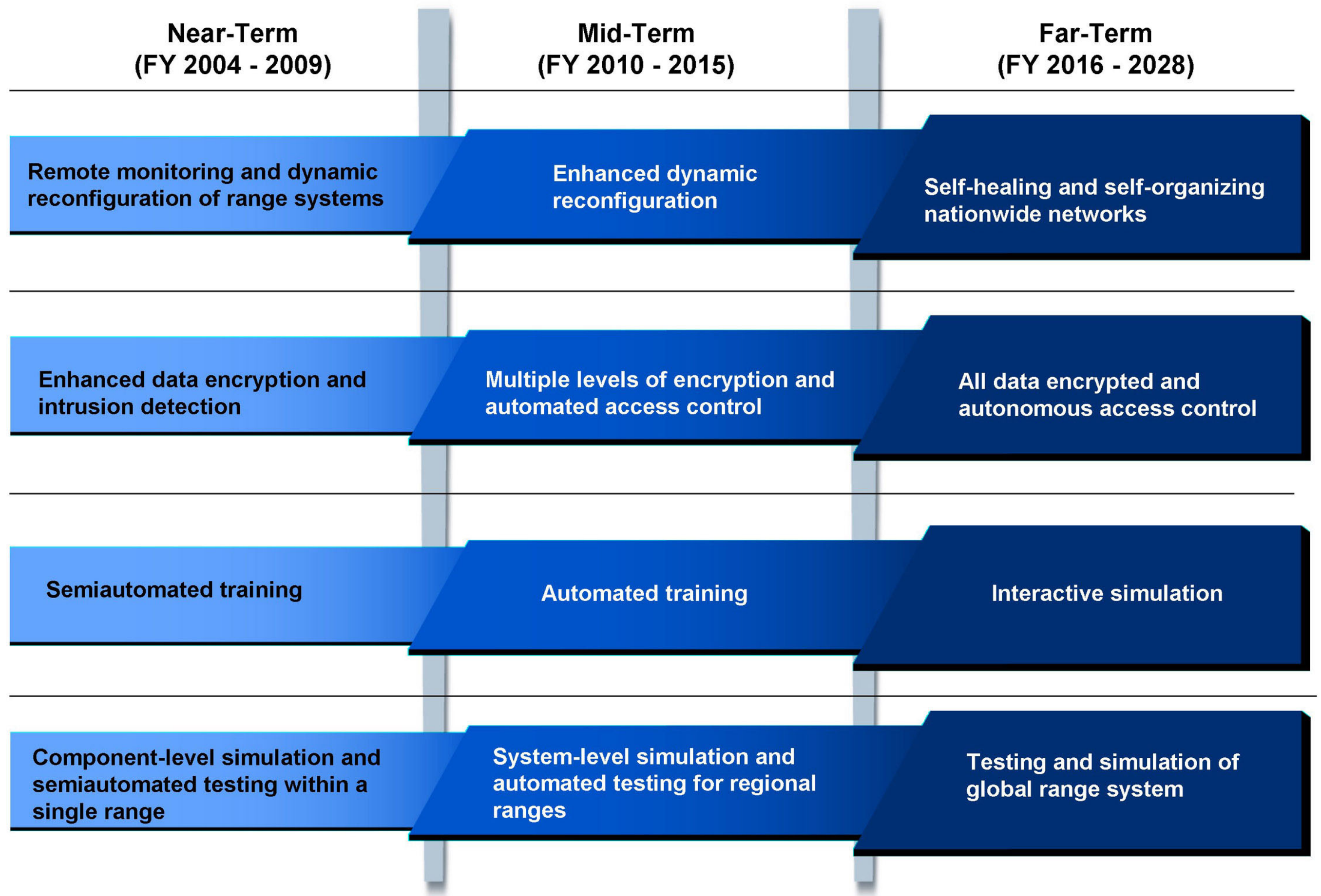

Figure ES-21 Capability Goals Over Time: Cross-Cutting Architecture (Sheet 1 of 2)

ARTWG envisions cross-cuttng performance measures evolving over time to result in commonality among the various subgroups, self-healing networks enhancing delivery of services, autonomous control, and interactive simulation and testing for all operators.

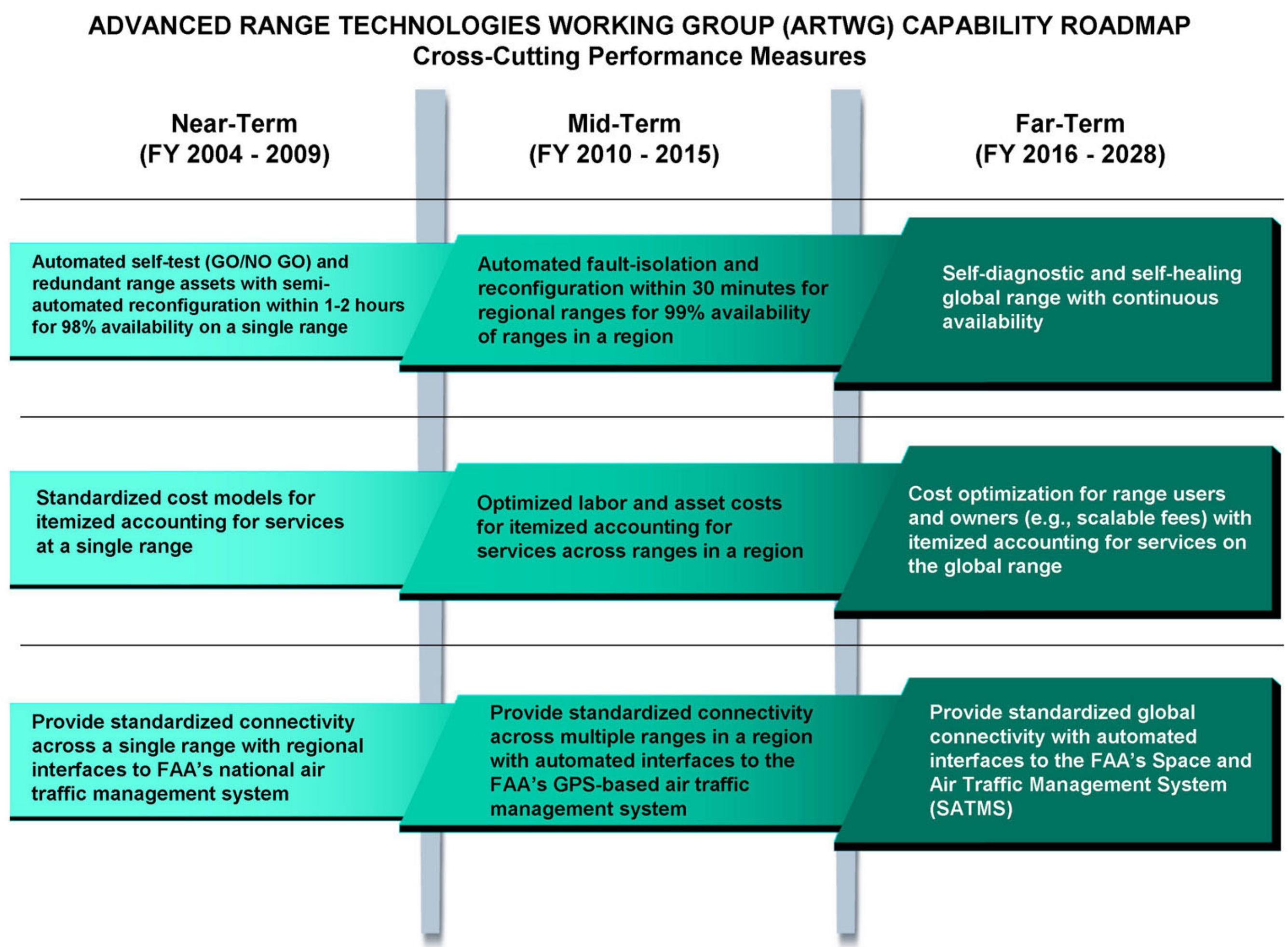

Figure ES-21 Capability Goals Over Time: Cross-Cutting Architecture (Sheet 2 of 2)

Key technologies for cross cutting architecture include automated systems, autonomous self-repairing systems, integrated system health monitoring and self-healing, software intelligent agents, data fusion, model and network-based embedded software for testing.

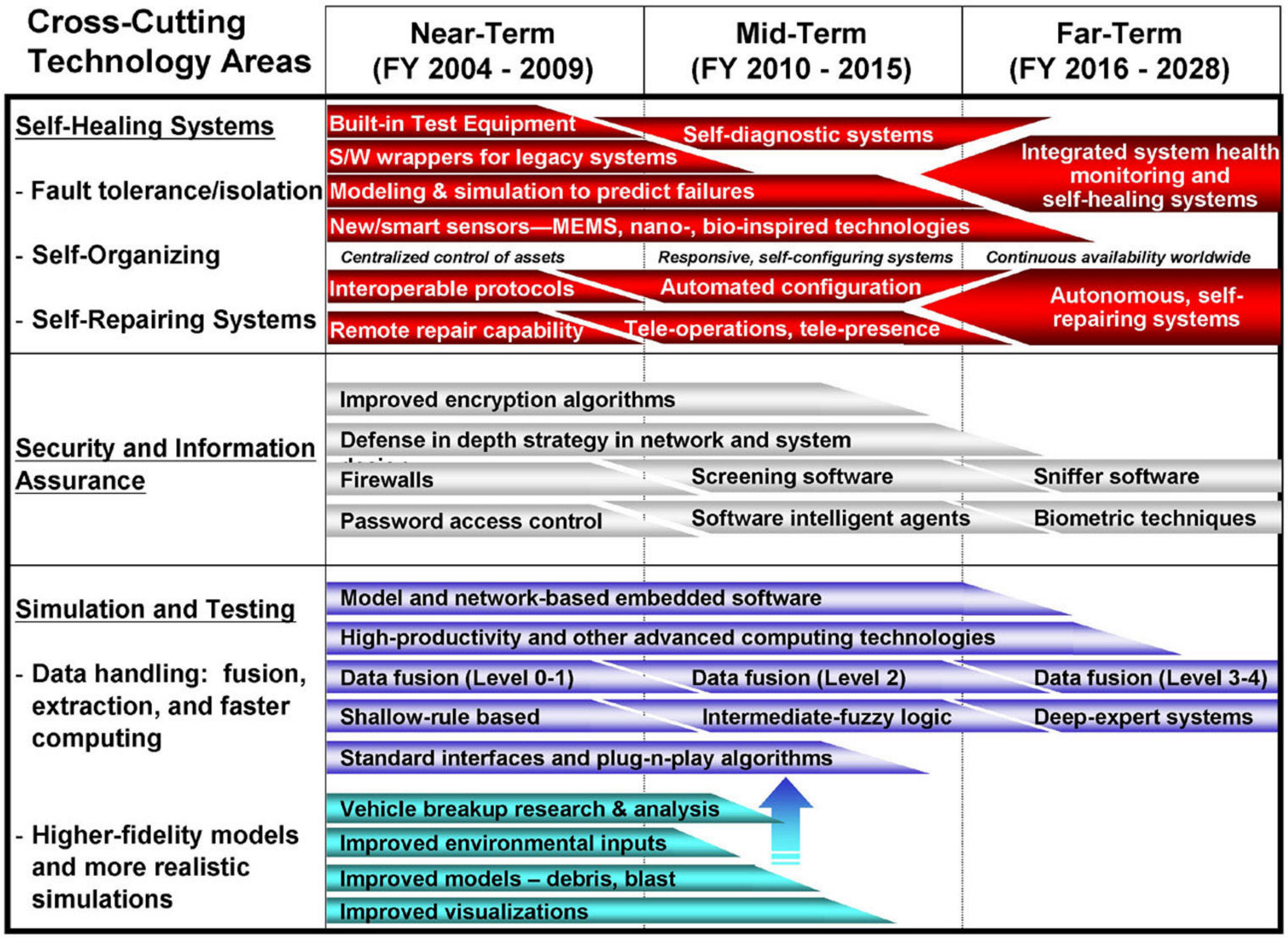

Figure ES-22 Technology Roadmap for Cross-Cutting Architecture

CONCLUSION AND RECOMMENDATIONS

Under the shared leadership of the USAF and NASA, the ARTWG has carried out the recommendation from the February 2000 interagency report on *The Future Management and Use of the U.S. Space Launch Bases and Ranges* to "develop a plan to examine, explore, and proceed with next-generation range technology development and demonstration." The capability and technology roadmaps presented in this report outline the technologies and demonstrations that should be pursued to enable the development of next-generation range capabilities that would "improve safety, increase flexibility and capacity, and lower costs for reusable and expendable launch vehicles" while also enabling support for emerging and projected test and evaluation missions.

The next step along the path toward developing more capable and efficient next-generation space launch and test ranges should focus on how to "proceed with next-generation range technology development and demonstration," as recommended by the interagency report.

- This should begin with a coordinated interagency effort to pursue the resources and authority necessary to orchestrate and conduct the technology development and demonstration activities outlined in the roadmaps.

- A coordinated interagency program involving multiple Government agencies should be created to direct and coordinate the development and implementation of a coherent overall strategy and plan for the nation's development of a primarily space-centric range capability supplemented by mobile range assets.

The most pressing range support issues that must be addressed and resolved in the near-term include:

- Access to and efficient use of frequency spectrum to support range functions and users.

- Target/miss distance measurement to support increasingly complex and diverse ballistic missile defense testing scenarios involving new geographic areas and multiple flight vehicles.

- Data relay issues associated with the use of satellites, particularly in geosynchronous Earth orbit (GEO), for range and user telemetry, communications, and command and control.

- Operationally responsive range to support rapid range launch and reconfiguration for the Operationally Responsive Spacelift (ORS) Program.

Both within and outside the range community, many opportunities for synergy exist among a variety of ongoing programs and research, development, and demonstration activities. These activities should be leveraged and pursued to enable the spiral development of new range capabilities that will be useful in incrementally improving the capability and efficiency of the nation's ranges. The ultimate goal of these efforts should remain focused on achieving the vision for a next-generation space launch and test range capability.

The following specific opportunities for synergy should be pursued as part of the overall strategy to pursue the technologies and demonstrations included on the ARTWG technology roadmaps:

- NASA, commercial, and DoD UAV technology and development efforts should be leveraged to assist the range community in affordably developing and demonstrating the use of mobile range assets to provide additional capabilities, capacity, geographic coverage, adaptability, and flexibility in providing range support when and where needed.

- Missile Defense Agency, Army, Navy, Coast Guard, and FAA interest in high-altitude airships for area surveillance should be leveraged and pursued as an area for synergistic development and demonstration, ultimately leading to low-cost, multiple-use mobile platforms for range instrumentation and assets.

- The range community should pursue synergistic opportunities to demonstrate new space-based and mobile range technologies and capabilities to provide support during flight test missions involving ballistic missile defense test scenarios and flight test activities being pursued under the joint DoD-NASA National Aerospace Initiative.

- The Defense Information Systems Agency's (DISA) Joint Interoperability Test Command (JITC) efforts to address efficient, interoperable data links and its expertise in interoperability certification could be leveraged by the range community in its efforts to apply technologies, approaches, and techniques to range Command, Control, Communications, Computers, and Intelligence (C4I) systems and capabilities.

- The Joint Advanced Missile Instrumentation (JAMI) program (developing flight and ground systems to track missiles and targets without relying on ground-based radar by utilizing GPS and guidance system data with existing telemetry links and infrastructure) should be viewed by the range community as a significant opportunity for synergistic development of on-board flight vehicle instrumentation to more efficiently interface with range systems, including demonstrations of new technologies and systems.

- DoD's Multi-Service Target Control System (MSTCS) Project (a modular, interoperable GPS-based system with high- and low-rate data links) should be leveraged to develop systems capable of providing precise tracking data for space launch and flight test vehicles as well as target control for vehicles involved in missile defense testing.

- The UAV Battlelab at Eglin Air Force Base (AFB) is pursuing significant developments in digital video data compression technology that should be explored and leveraged by the range community as a means of making more efficient use of frequency spectrum on space launch and flight test ranges.

- The Naval Research Laboratory (NRL) has efforts to develop wide bandgap semiconductor materials, and technologies should be leveraged by the range community to include prototype hardware to demonstrate use of higher frequencies for telemetry, communications, and command and control in conjunction with other range technology demonstration activities.

- The range community should engage with the Transformational Communication Office (TCO) to ensure its plans and programs include future range systems and requirements. This program is intended to remove bandwidth constraints through a new network of high-capacity satellites for use in combination with the Global Information Grid.

- FAA's continued NAS modernization efforts have many similar capability needs and technology development areas such as CNS, weather, and decision support tools. Through related technology needs, the possibility of sharing common assets (radar, communications networks, etc.) and operational dependencies, a common air and space transportation system is expected to evolve.

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INTRODUCTION

INTRODUCTION

In the spring of 1999, the Assistant to the President for National Security Affairs and the Assistant to the President for Science and Technology formed a White House-led Interagency Working Group (IWG) to review the future management and use of the primary U.S. space launch bases and ranges. On February 8, 2000, the White House released a report titled, "The Future Management and Use of the U.S. Space Launch Bases and Range*s*." This report was formally approved by the Assistant to the President for National Security Affairs, the Assistant to the President for Science and Technology, and the Director of the Office of Management and Budget, the Secretaries of Defense, Commerce, and Transportation, the FAA and NASA Administrators, the Secretary of the Air Force, and the Director of the National Reconnaissance Office. In the spring of 2000, its recommendations were endorsed by the President. The IWG report recommended "the Air Force and NASA should develop a plan to examine, explore, and proceed with next-generation range technology development and demonstration, with a focused charter to improve safety, increase flexibility and capacity, and lower costs for reusable and expendable launch vehicles." In response to this recommendation, NASA and the Air Force established the Advanced Range Technologies Working Group (ARTWG).

PURPOSE

The purpose of the ARTWG is to cooperatively develop a national vision through a broad coalition of space transportation industry experts and stakeholders. The ARTWG provides a forum and framework to formulate a strategy and identify enabling technologies needed to achieve that vision. This approach is based on the belief that effective planning to facilitate range growth depends both on inviting all stakeholders to participate in the discussion and on having a way to organize the expression and recording of ideas. In this process, the ARTWG is working to eliminate duplication of effort while increasing synergy.

Representation from all aerospace sectors with an interest in range development ensures the applicability of the technologies to users' requirements. Membership includes NASA Centers/programs, private industry, current and future spaceport and range customers, operators and developers (including existing and emerging launch services providers), commercial and emerging spaceports, academia, states, the Federal Aviation Administration (FAA), Department of Defense (DoD), and Department of Commerce (DOC).

The ARTWG serves as a central national forum for identifying future range technology needs for a broad spectrum of space launch and test ranges. The ARTWG was chartered to:

- Identify space launch and test range technology needs for a broad spectrum of ranges.
- Develop a roadmap (plan) that contains project options for the development and demonstration of range technologies that will meet the needs of the existing and future ranges established by Federal policy or by other U.S. entities.
- Develop plan approaches and options for reaching the next-generation advanced ranges of the future.

The ARTWG focus includes:

- Orbital and suborbital ranges tracking expendable and reusable launch vehicles.

- Government and nongovernment, existing and future ranges.

The ARTWG has subdivided the “Range” into seven technical focus areas, which include:

- Tracking and Surveillance
- Telemetry
- Communication Architecture
- Range Command and Control Systems (RCCS)
- Decision Making Support
- Planning, Scheduling, and Coordination of Assets
- Weather Measurement and Forecasting

The Advanced Spaceport Technologies Working Group (ASTWG) addresses spaceport (ground launch site) technologies and also pulls the Cross-Cutting Architecture Roadmaps that were consistent in many technology focus areas. The ARTWG is coordinating its activities with the ASTWG so that two key areas of the macro space transportation system, Range and Spaceport, are addressed (Figure 1).

Spaceport and range technologies will help enable the transition toward more of the total time, cost, and schedule associated with space transportation being dedicated to flight instead of ground processing.

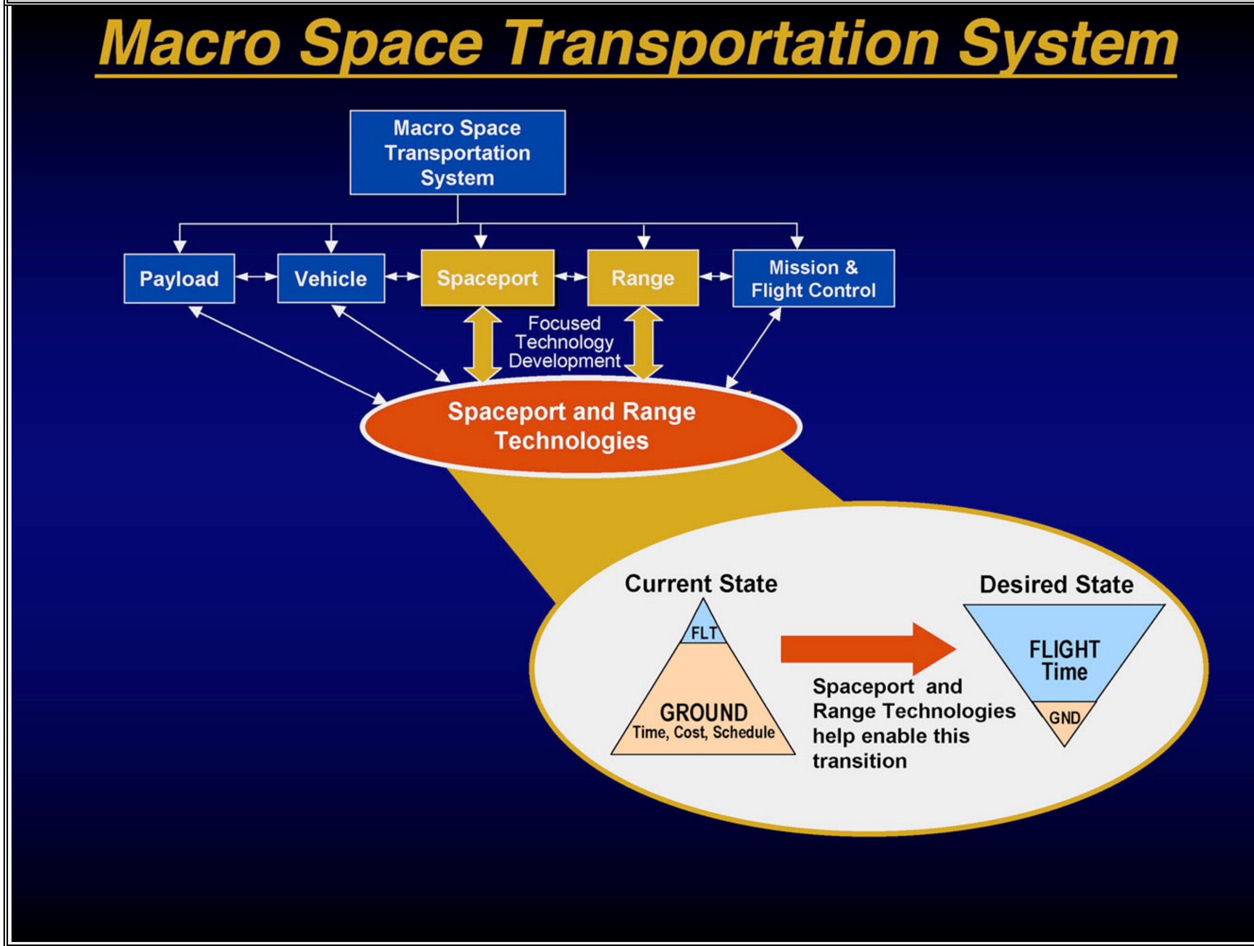


Figure 1 Spaceport and Range Elements of the Macro Space Transportation System

SCOPE

The scope of the ARTWG efforts is defined by understanding the overall components of the overall space transportation system, as depicted in Figure 2:

- Vehicle: A manned or unmanned spacecraft designed to orbit the Earth, transit the space environment, or travel to celestial objects for the purpose of delivering payloads or crew into space, or returning payloads or crew from space.
- Payload: The load that is carried by a spacecraft that consists of things related directly to the flight mission as opposed to things that are necessary for operations.
- Spaceport: The functions, assets, and resources required to prepare space vehicles and their payloads (including crew and passengers) for departure, arrival, and reflight preparations as applicable.

- Range: The volume through which the vehicle must pass on its way to and from Space and all of the command, tracking, and monitoring functions and assets required to meet the range mission.
- Mission and flight control: A facility containing personnel and equipment that controls, monitors, and coordinates the launch event, communicates with the vehicle and payload, performs data analysis and decision making, and monitors vehicle and/or payload systems through flight termination.

The ARTWG focused on the range component of the overall space transportation system.

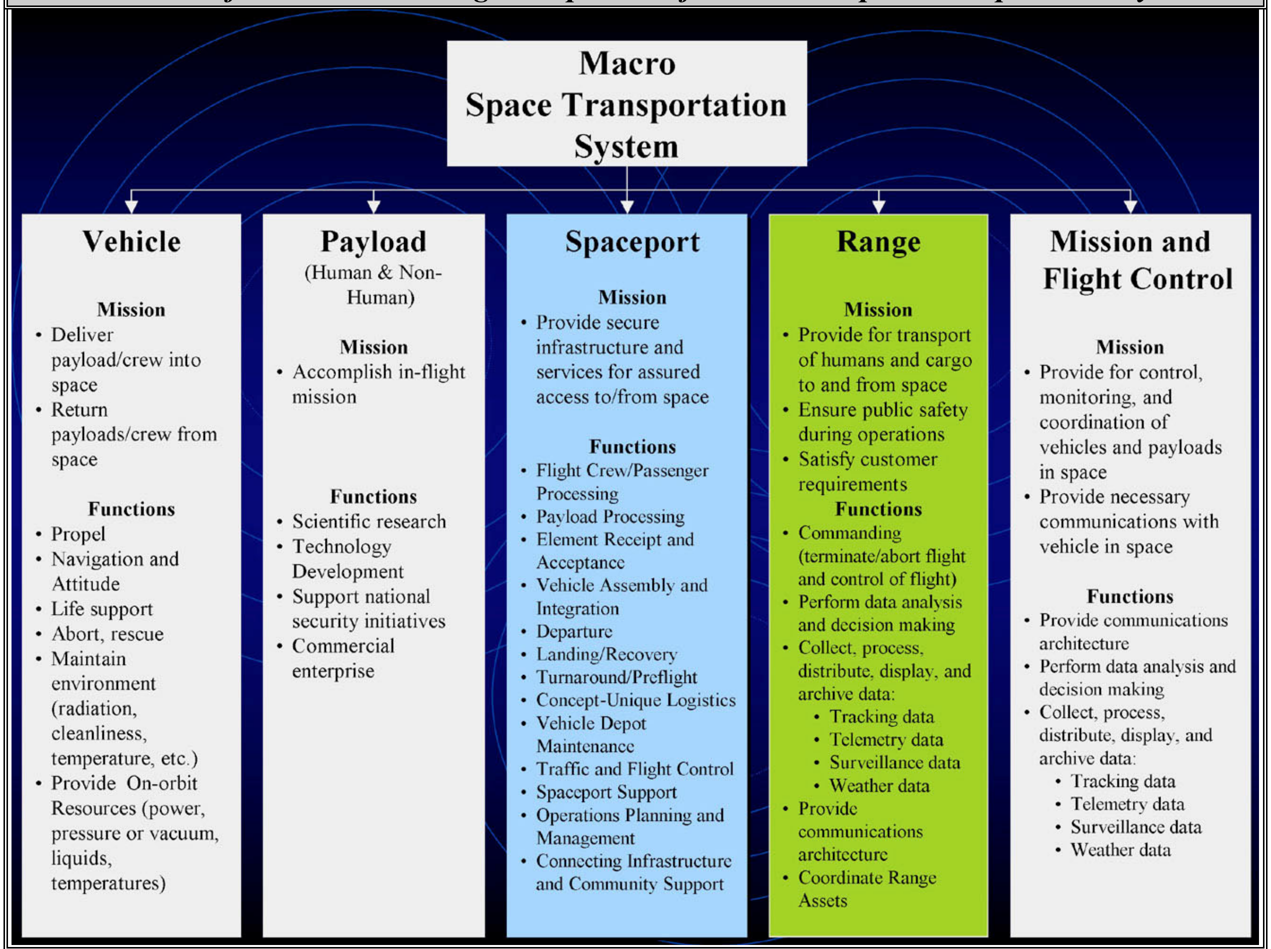


Figure 2 ARTWG Addresses Ranges as Part of the Macro Space Transportation System

Figure 3 depicts the Range Volume as specified by the ARTWG community. The focus of the ARTWG is the piece of this figure (Range Volume and the systems needed to launch through this volume of space) (e.g., Tracking and Surveillance). The categories and functions of range support assets and capabilities that are likely to be required for the near- to far-term were listed as part of the definition of "range facilities and systems" in the February 2000 report titled, "Interagency Report on the Future Management and Use of the U.S. Space Launch Bases and Ranges."

The air and space volume needed to conduct a launch or test operation is only controlled by the Range when it is needed.

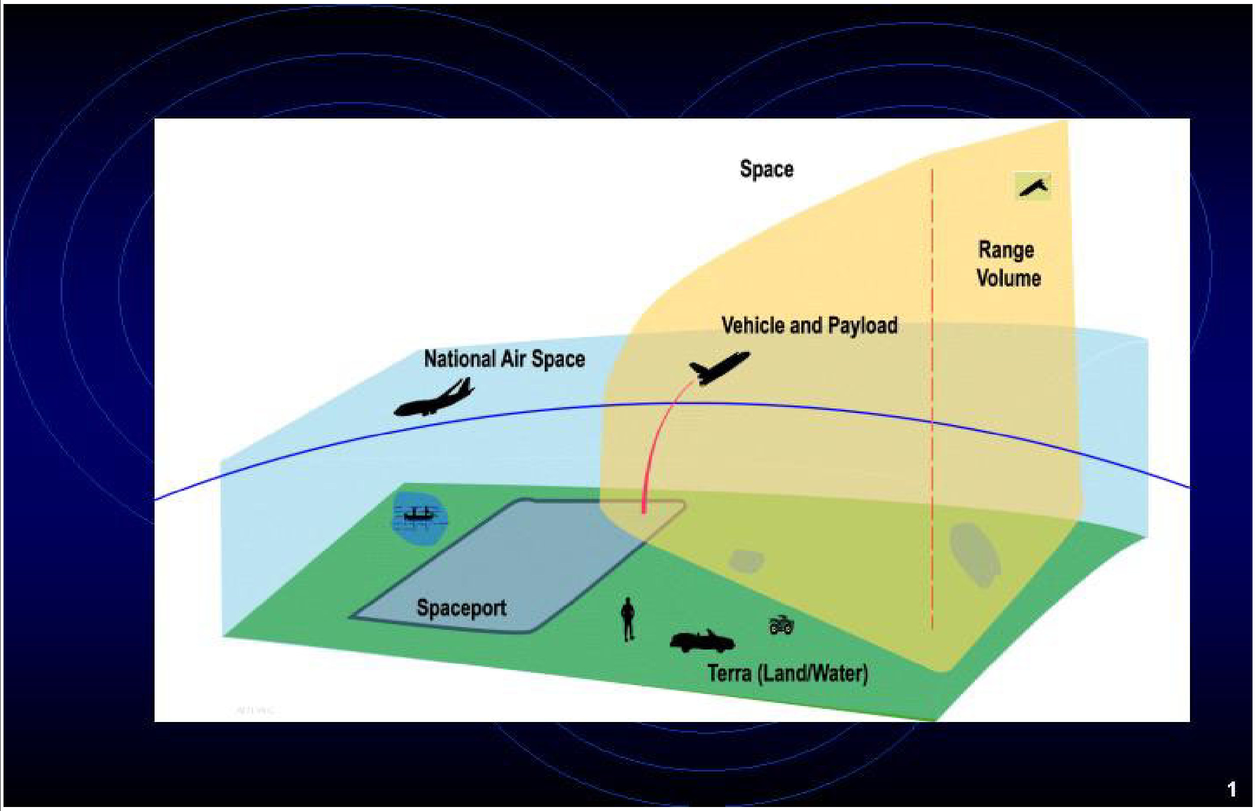


Figure 3 The Range Environment

> *"Range facilities and systems include sensor and command and control capabilities necessary to safely conduct national security, civil, and commercial space launch operations, as well as T&E of land- and sea-based ballistic missiles and other systems. Range facilities and systems also include buildings, instrumentation, support equipment, associated utility systems, and command and control networks, such as:*
>
> *Range operations control centers providing command and control, and communications.*
>
> *Radar systems and other metric tracking assets.*
>
> *Optical tracking, video and photographic assets.*
>
> *Telemetry receivers and processing systems.*
>
> *Command transmitters and other safety system assets.*
>
> *Weather measurement and prediction capabilities.*
>
> *Communications systems and switching nodes to distribute voice and video and data.*
>
> *Airspace, sea, and land area surveillance assets."*

Future next-generation range functions will be driven by the needs of various range stakeholders, including spaceport operators; launch vehicle and payload designers, developers, and operators; range administrators; and oversight and regulatory arms of the Federal Government (see Figure 4). Each stakeholder group has its own set of needs today and for the future. Some of these needs overlap, including the desire for reliable, responsive and cost-effective range operations. Others are more unique to individual stakeholder groups. For example, DoD is more interested than some of the other stakeholders in the ability to responsively launch and operate spacecraft in orbit, requiring responsive range support as well. The following table summarizes the results of the ARTWG's assessment of the various range stakeholders' current and future needs for range capabilities.

A variety of range stakeholders in several categories have some common and unique needs today and for the future.

Affordable Access to Space

Common Needs: safety, security, resource protection (including physical security, force protection, and information assurance), lower costs, greater flexibility, increased capacity and concurrent operations, shortened flight plan approval, effective data handling and information systems.

Stakeholder Group	Stakeholders	Today's Needs	Future Needs
Spaceports (Customer)	• Federal Spaceports • State Spaceports • Commercial Spaceports • Developing Spaceports	• Flexible, robust, and efficient systems that can support high-flight rates • Shared-use infrastructure that supports concurrent operations • Cost-effective systems • Opportunities to create viable new spaceports • Effective master planning	• Cost-effective • Ability to access a variety of orbits • Effective master planning • Multimode transportation • Effective data handling and information systems

Launch Vehicle Designers, Developers, Providers, and Operators (Customer)	• Government
	  • Military
	  • Civil
	  • Other
	• Commercial
		• Responsive and robust range
		• Engineering data during development
		• Reliable and flexible launch dates
		• Effective data handling and information systems
		• Effective regulatory coordination
			• Efficient, cost-effective, responsive, and robust range
			• Evolving regulatory process in space with vehicle developments
			• Less impact to vehicle systems
			• Vehicles with short turnaround time
			• Simplified/standardized system interfaces

Payload Providers and Developers (Customers)	• Government
	  • Military
	  • Civil
	  • Other
	• Commercial
	• Nonprofit (e.g., academia)
		• Responsive and robust range
		• Reliable and flexible launch dates
		• Rapid access to space (DoD)
		• Highly reliable vehicles
		• Increased standardization between vehicle and operations
			• Responsive and robust range
			• Large surge launch rate capability
			• International range compatibility
			• Short notice launch and landing world wide
			• Improved coordination

Range Administrators (Owners and operators)	• Military • Civil • Other	• Consistent compliance processes • Increased automation • Low turnaround time between launches • Highly reliable vehicles	• Reduced asset costs • Full integration with FAA ATC, space surveillance network • Interoperability between ranges • Align range to support routine operations or test and evaluation • Global coverage
Federal and State Governments (Funding and oversight)	• U.S. Government • State Governments • Local Governments	• Economic competitiveness • Environmental stewardship • Standardized and simplified Government policies • Workable, effective regulations	• Routine space transportation • Appropriate regulatory processes that meet public safety and commerce needs • International agreement on Range operations

Figure 4 U.S. Range Stakeholders' High-Level Needs

Two primary types of missions are likely to require support from space launch and test ranges in the future. They are:

- Space Launch and Recovery Operations – Including, for example, expendable launch vehicle (ELV), Space Shuttle, and reusable launch vehicle (RLV) launch and recovery operations, including suborbital RLVs and entrepreneurial systems, for a wide variety of national security, civil, and commercial missions, and launches and recovery operations involving the Orbital Space Plane (OSP) and Next-Generation Launch Technology (NGLT) being developed under NASA's Space Launch Initiative (SLI), part of its

Integrated Space Transportation Plan (ISTP). In the far term, it is envisioned that suborbital RLV's (SRLV) will emerge and also "drive" the space-launch industry market.

- Test and Evaluation (T&E) Mission – Including, for example, aeronautical flight testing of civil and military aircraft and flight systems, various types of guided missiles, and unmanned aerial vehicles (UAVs) with a variety of possible applications; intercontinental ballistic missile (ICBM) and submarine-launched ballistic missile (SLBM) T&E missions; orbital and suborbital flight demonstrations for DARPA's operationally responsive FALCON Program, Ballistic Missile Defense Systems (BMDS) T&E, and flight testing of hypersonic missiles, propulsion systems, and vehicles - a cooperative effort across DoD and NASA. Although this mission is not the primary focus of the ARTWG, the technologies being identified are synergistic with the advancements needed in this community (see Figure 5).

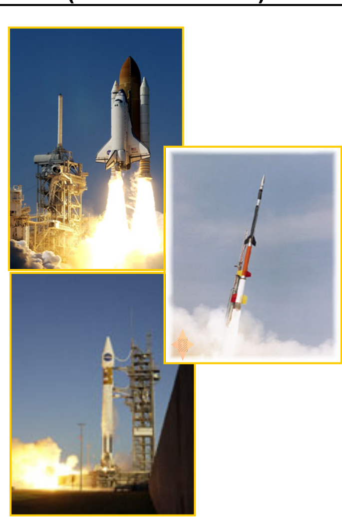
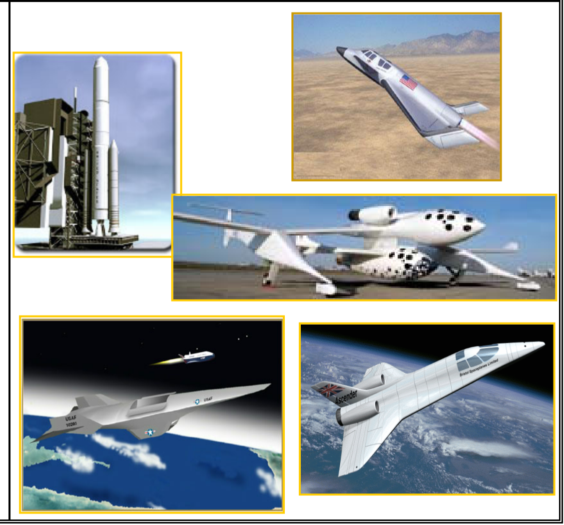
Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Far-Term (FY 2016 - 2028)
		

Figure 5 Examples of Future Space Launch Vehicles Requiring Range Support

While space launch and T&E missions are challenging for the space launch ranges to support, the most "stressing" technical challenges will be for future SRLVs, and the currently planned T&E activities associated with the planned flight testing of ballistic missile defense systems involve multiple high-speed targets and interceptors being launched from multiple locations, including ships and aircraft, at widely dispersed geographic locations. In such cases, each launch location requires surveillance to ensure that hazardous areas are cleared of unauthorized people and vehicles for safety and security reasons. In addition, these test scenarios require high data-rate telemetry, optical coverage, and precise metric tracking for each of the vehicles involved in the test scenario.

All these types of range support are required to evaluate how well the interceptor systems are able to discriminate between decoys and incoming ballistic missile and reentry vehicle targets and how effectively and reliably they are able to engage and destroy the targets. Scheduling and coordinating the use of range assets to support such a test require substantial communication capabilities to transfer voice, video, and data among multiple locations spanning nearly half the globe. The data being collected must also be available for real-time and posttest processing and display in multiple control centers and user locations.

On the other hand, entrepreneurial ventures building capabilities to access space for commercial purposes and the state government and private spaceports being pursued to support them tend to have needs for simpler, lower-cost, and streamlined range support to enable routine operations. All these types of range-supported launch activities (i.e., space launch, SRLV, and T&E) need to be addressed when identifying the technologies for the next-generation range system.

APPROACH

The ARTWG divided the main functions of next-generation space launch and test ranges into seven categories and formed ad hoc subgroups consisting of range and technology experts from across the country to address each, as follows:

- Tracking and Surveillance: Range tracking systems consist of hardware, software, and equipment required to transmit, receive, process, and display time-space position information (TSPI) required for range safety purposes, engineering flight analysis, and debris recovery and failure analysis in the event of a mishap. This includes real-time TSPI on flight vehicles and/or debris from on-board, ground-based, or space-based assets through all phases of flight where the vehicle can pose a hazard to property or people. Area surveillance includes detection of people and vehicles in those land, sea, and air areas where toxic and/or debris hazards may exist as a result range-supported operations. Clearance of such areas may be required to ensure that transient people, ships, aircrafts, or other vehicles do not increase risk beyond acceptable levels during range-supported operations.

- Telemetry: Hardware and software used to receive, process, archive, and display data received from launch vehicles and their payloads during ground processing, flight, and recovery or landing. This information will also be used as a source of data for the reconstruction of events in the case of a mishap.

- Communication Architecture: Communication systems provide acquisition and distribution of voice, video, data, and timing as well as support services to internal and external range/spaceport customers during prelaunch, launch, and landing activities. These systems also serve as the primary interface between range subsystems (Telemetry, Range Command and Control, Tracking and Surveillance, Decision Making, Scheduling and Coordination of Assets and Weather).

- Range Command and Control System (RCCS): The Range Command and Control System consists of the vehicle and ground hardware, software, and other resources required to safe/terminate launch vehicle flight in order to ensure the safety of the general public, workforce, and property. The RCCS provides the manual, automatic or autonomous capability to safe/terminate launch vehicle flight when it poses unacceptable risk to people or property. The RCCS may also provide remote guidance, attitude, or payload control and other uplink communications functions for select launch vehicles.

- Decision Making Support: Decision making is the expertise and supporting technologies used to provide "readiness" of flight preparations and real-time flight safety operations for launch, Return to Launch Site (RTLS), and landing. Flight preparations include flight plan analysis and approval and generation of an instrumentation coverage plan. Real-time flight safety operations use inputs from weather, tracking, telemetry, area surveillance, USSTRATCOM satellite catalog, and FAA Air Traffic Control systems to generate situational awareness of the flight vehicle and other objects within the hazard area and ascertain acceptability of the in-flight vehicle's path.

- Planning, Scheduling, and Coordination of Assets: Hardware, software, and resources used to provide deconfliction and scheduling of all internal/external range assets, airspace, and frequencies necessary to meet range user requirements. This includes interactions with local or regional frequency managers for frequency spectrum allocation, monitoring, local or regional airspace managers for special use/restricted airspace, and coordination with Federal Aviation Administration (FAA) officials for use of the National Airspace System.

- Weather Measurement and Forecasting: Systems are required to rapidly detect, evaluate, and communicate to vehicles, crews, and decision makers, in near real time, those weather parameters, forecasts, and warnings that are key to safe, efficient operations. Operations include ground processing, ascent, flight, and recovery. Weather parameters include upper-level winds for vehicle loads and trajectory shaping; surface winds, thermal structure and natural lightning for ground processing and toxic hazard decisions; triggered lightning potential to protect sensitive electronics; cloud thickness, coverage and height, and precipitation for visibility and thermal protection systems; and electron, proton, and x-ray flux to assess flight hazards to vehicle, crew, and payload systems. All weather data must be archived to permit accurate assessments of system design and operational issues. Consultation with weather personnel while designing operational systems or processes, to ensure weather impacts and capabilities are properly considered, is essential to reducing the impact of atmospheric phenomena on Range and Spaceport customers. To cost effectively develop and implement new technologies, customers must be directly involved in setting goals and priorities through a process similar to that currently exemplified by the NASA/USAF/NWS Applied Meteorology Unit.

- Cross-Cutting Architecture: Common technology areas, which cross-cut the server subfunction areas, were pulled into one cross-cutting architecture roadmap section (for example, encryption).

Recognizing the ARTWG as an interagency program formulation effort that involved a diverse set of stakeholders, ARTWG followed a three-pronged approach to developing the ARTWG Technology Plan (see Figure 6). The three efforts focused on:

1. Build and follow a Strategic Program

2. Build the ARTWG Technology Plan

3. Build the ARTWG Community

ARTWG undertook an interagency program formulation effort with a diverse set of stakeholders by following a three-pronged approach to developing Technology Roadmaps.

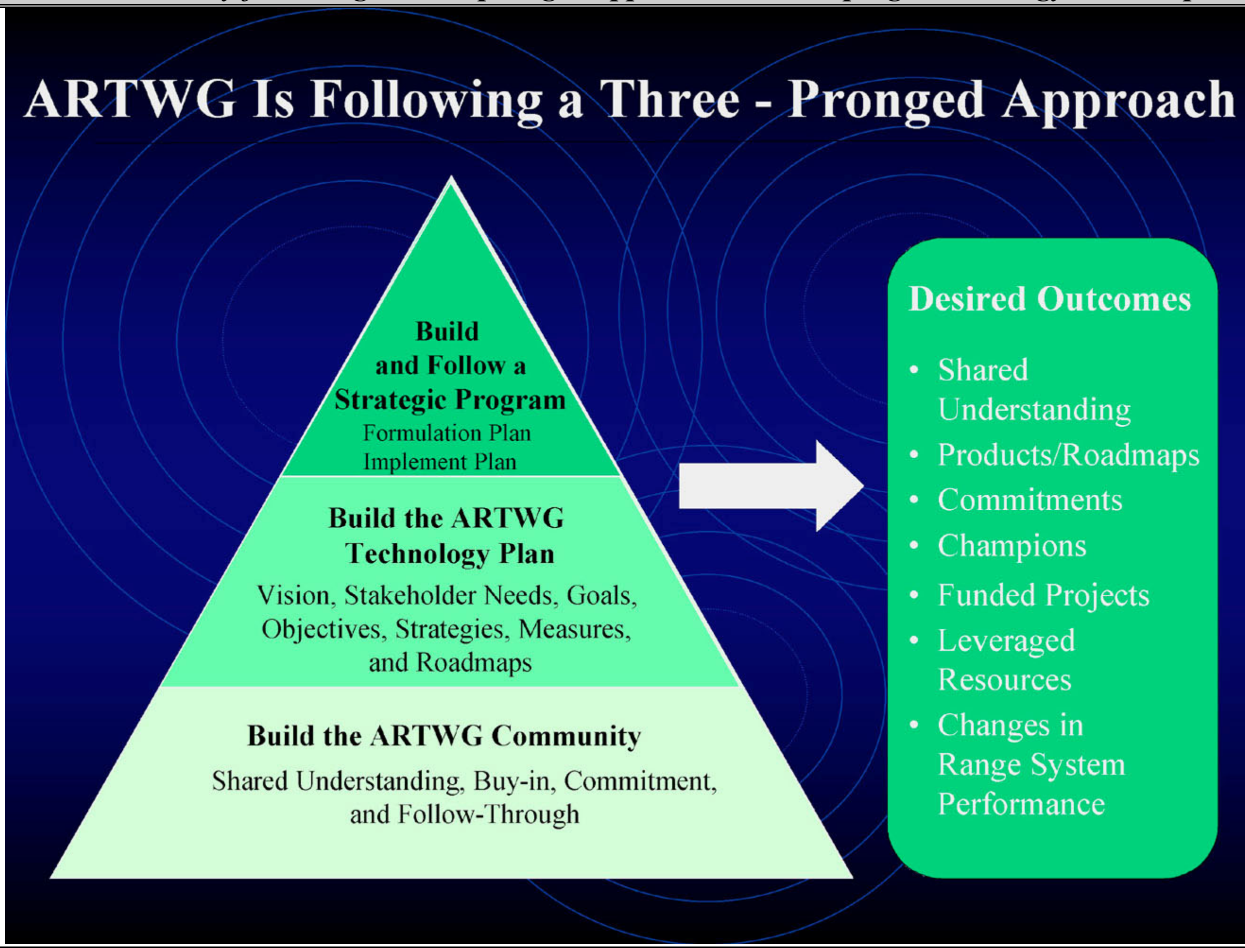


Figure 6 ARTWG's Three-Pronged Approach

To accomplish the scope of the ARTWG charter, ARTWG developed an integrated approach to ensure all interested stakeholders would be able to participate. To build a broad level of involvement, the ARTWG undertook the following actions:

- Implemented a shared leadership structure across agencies and organizations.
- Invited participation within the working groups.
- Conducted open meetings, conferences, and workshops.

Some specific ways in which the shared leadership structure was implemented include:

- Co-chairs were appointed by both the Air Force Space Command and by the NASA Office of Space Flight.

- The ARTWG is composed of U.S. citizens, including representatives from Federal agencies, state and local governments, industry, professional associations, and academia whose organizations are engaged in providing launch range services, developing range technologies, or customers of U.S. launch sites.

- Co-chairs are empowered to establish standing and ad hoc teams and panels consisting of Government and/or industry and academia membership. Federal policy/law will be adhered to in establishing and conducting such activities and in defining tasks and appropriate participation. NASA will seek to ensure diverse interests are represented.

- The ARTWG is conducting meetings annually or when determined by the co-chairs.

- The ARTWG roadmaps and recommendations will be reviewed by senior Government representatives, including:

    - Senior Steering Group - Representatives from NASA, FAA, OSD, and USAF to provide guidance to the Executive Steering Committee and the ARTWG Leadership Team. Members will be appointed by NASA and the USAF.

    - Executive Steering Committee - Senior Representatives from Federal organizations, such as NASA, USAF, FAA, OSD, and others as appointed to provide senior agency guidance and recommendations.

It is envisioned that the products of the ARTWG will become the national roadmaps for the development of future next-generation space launch and test ranges.

ARTWG activities to date include:

- Kickoff symposium at NASA Kennedy Space Center in January 2002

- One year of effort managed by the co-chairs of seven separate subgroups

- Second symposium in September 2002 in Colorado Springs, Colorado

- Seven mini-retreats, one for each subgroup

- Third Symposium in May 2003 in Orlando, Florida

- Centralized management by ARTWG leadership to create and integrate the technology roadmaps and this report

All ARTWG efforts were focused on first defining the vision for future range capabilities and then establishing goals and objectives for each function and subfunction within each of the seven technology focus areas. Next, each subgroup outlined a series of technical challenges and approaches to address each challenge. The roadmaps that resulted from the process of defining goals (G), objectives (O), technical challenges (TCH) and approaches (A) are referred to as GOTCHA charts.

VISION FOR IDEAL FUTURE SPACE LAUNCH AND TEST RANGES

VISION FOR IDEAL FUTURE SPACE LAUNCH AND TEST RANGES

Over the past 25 years, a variety of studies have assessed the advantages of various alternative range architectures and approaches. Most recently, the Extended Range Concept Definition Study - sponsored by the California Space Authority and conducted between September 2001 and September 2002 by Booz Allen Hamilton under contract with DoD's Information Assurance Technology Analysis Center - built on this body of range-related studies. It described and evaluated various options and recommended a next-generation space launch and test range based on evaluation criteria established through interaction with range stakeholders. The ARTWG adopted the elements of this study in the course of defining its vision for the future.

A primarily space-centric range supplemented by mobile assets will improve the adaptability and flexibility of future ranges in terms of their ability to accommodate higher- or lower-than-projected workload, provide expanded geographic coverage to a global scale, and provide the ability to increase capacity as needed by using mobile assets for supplemental coverage where and when needed (see Figure 7). By leveraging synergistic technologies and approaches and by sharing use of systems, such a future range would be less expensive to operate and maintain.

A primarily space-centric range supplemented by mobile range assets would improve adaptability, flexibility, and geographic coverage while providing capacity as needed.

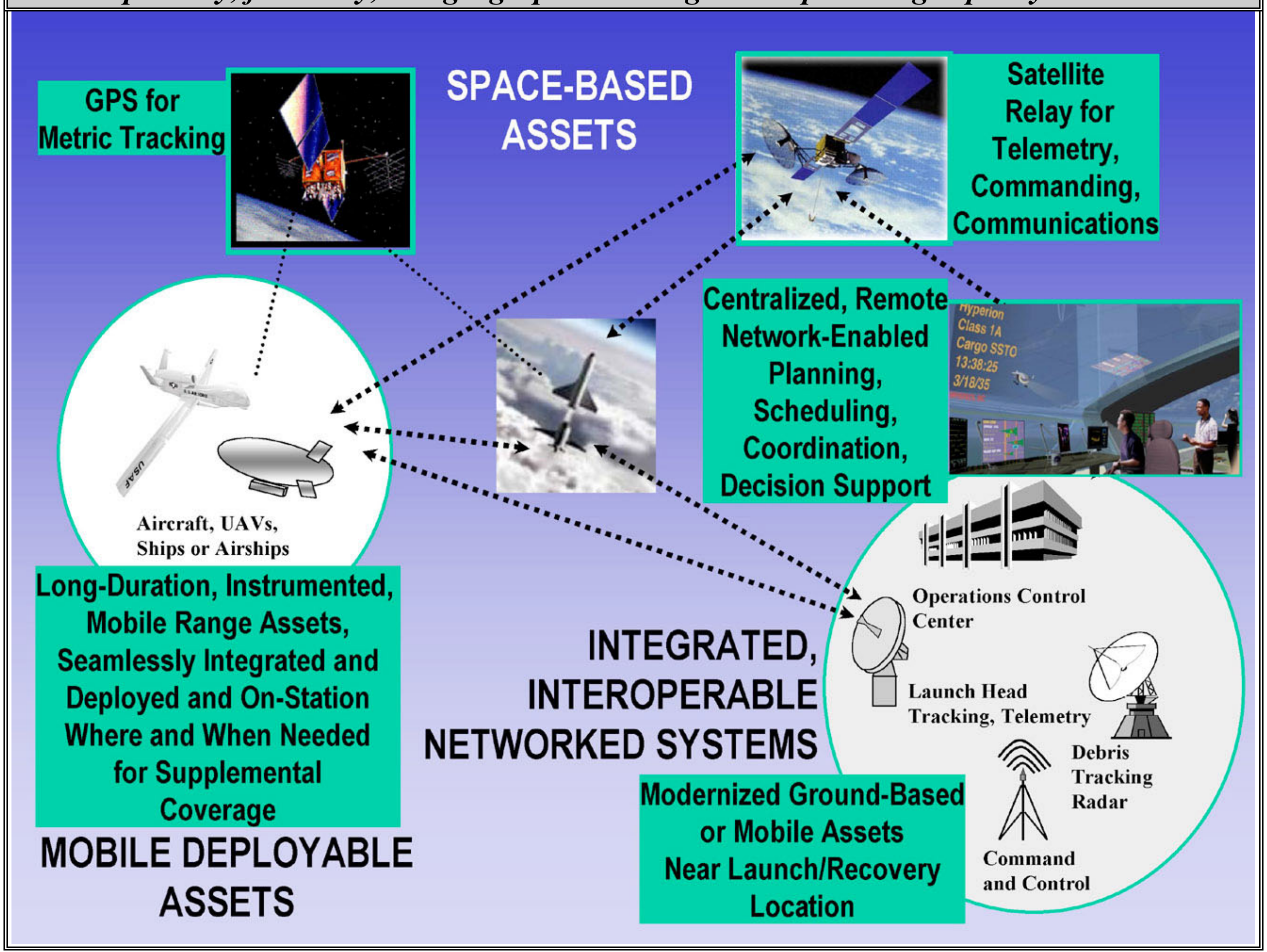


Figure 7 Vision for Future Global Launch and Test Range Architecture

Such a future range uses GPS for tracking data and communication satellites for relaying telemetry and commands between flight vehicles and range assets, as well as for communications between and among range control centers and range assets. The vision maintains a robust, two-way data link with flight vehicles for both telemetry and commanding. Such a future range also incorporates modernized ground-based or mobile range assets to provide up-range tracking of debris and telemetry and commanding capabilities required to meet safety standards without the time delay associated with using satellites. Broadband relay satellites serve as the primary telemetry and commanding capability for down-range operations requiring hemisphere- or global-scale range coverage, where the time delay can be accommodated without adversely impacting the safety of range-supported operations. Mobile range assets provide additional flexibility to supplement range coverage and capabilities in cases when specific missions require particular range support functions that could not be met by satellites alone.

Developing such a future range architecture with both space-based and mobile range assets improve adaptability, flexibility, and geographic coverage of range capabilities along with expanded capacity as needed to meet projected missions while enabling incremental development and technology demonstrations at relatively low cost and risk.

CONCEPT OF OPERATIONS (CONOPS) FOR FUTURE RANGE VISION IN 2028

To support prelaunch processing and flight activities, the future range as envisioned by the ARTWG would provide weather modeling, measurement, and forecast information networked together using integrated inputs from a variety of range-specific and regional weather sensors and models. Area surveillance data for safety, security, and mission assurance in any potentially hazardous land, sea, or airspace areas, and along the entire intended flight path, would be provided by a variety of multiuse sensors and platforms, including FAAs air traffic surveillance capabilities, using modernized ground-based instrumentation and airborne systems aboard UAVs or high-altitude airships (HAAs). Data from these crucial systems and sources will be fused to provide real-time situational awareness and augment decision support, including modeling and simulation, as well as automated planning, scheduling, and coordination of range assets and operations. These tools are needed for alternative route planning, including use of controlled airspace, and collision avoidance with objects in space.

Beginning prior to first motion of a launch or flight test vehicle, an onboard GPS receiver and Inertial Measurement Unit (IMU) provide metric tracking and TSPI data for integration with the vehicle telemetry stream for transmission to ground-based range assets near the launch and recovery area while within line of sight. Also prior to first motion, the vehicle's onboard telemetry and commanding system also establishes a two-way data link with a communication satellite and maintain it as the vehicle proceeds over the horizon from the launch or take-off point. Vehicle telemetry data would be transmitted to this satellite system, where it is relayed back to a ground station and then, via communication networks, back to the Range Operations Control Center (ROCC) and to user locations. During flight, telemetry (including metric tracking data) and commanding continue to be transmitted for receipt and processing by various range assets, including ground-based receivers near launch and recovery locations, satellites providing global coverage, and mobile platforms (e.g., UAVs and HAAs) deployed for supplemental coverage as needed to support particular missions or activities. Examples of situations when such supplemental mobile assets might be needed include ballistic missile intercept test scenarios involving multiple vehicles in flight simultaneously from multiple locations, test flights requiring higher than usual data rates, or operations requiring additional tracking coverage based on optical, IR, UV, multispectral, radar, or other types of instrumentation or phenomenology.

Commanding (i.e., from control center to flight vehicle) is transmitted directly from ground-based transmitters up-range near the launch and recovery area, while the vehicle is within line of sight. As the vehicle proceeds over the horizon, the command link is maintained along with the telemetry link through satellites and mobile assets as needed. In some cases, the need for commanding relays will be reduced by relying on vehicle autonomy instead of relying completely on control from the ground to ensure the safe operation of vehicles and mobile range assets flying on the range.

The range of the future will offer telemetry, command, control, and location information from flight vehicles and deployed range assets by use of the global information grid and will operate like an "internet in the sky." This capability makes efficient use of frequency spectrum and bandwidth. This enables the secure and timely transfer of data at rates that are scalable and selectable as required to support specific missions and activities. Communication systems to distribute voice, video, timing, and data will connect ranges globally allowing for similar scalability and accommodating data rates required by the user and operator efficiently using frequency spectrum and bandwidth. A variety of technologies and approaches can contribute toward achieving this desired end state, including for example, advanced network technologies and jam-resistant communications, including new breakthroughs with network, Quality of Service (QoS), signal processing (including compression, modulation, error correction, equalization, etc.), laser and free space optical communication technologies, and alternative approaches to using frequency spectrum (e.g., ultra-wideband, sensing spectrum need changes and autonomously switching to unused frequencies processing signals to take advantage of multipath interference, polarization, etc.).

In the context of this future range vision, some of the specific capabilities associated with each of the range functions addressed by the ARTWG include the following:

- Tracking and Surveillance: For the far-term, tracking and surveillance equipment will interface with the FAA’s Space and Air Traffic Management System (SATMS), allowing seamless and fully integrated space and aviation operations in a modernized, efficient National Airspace System. Relying primarily on seamlessly integrated GPS and on-board inertial systems for metric tracking enables global range coverage for simultaneous operations. Integrated area surveillance data aids in providing real-time situational awareness within selectable regions worldwide.

- Telemetry: Future ranges provide global coverage using space-based range assets, supplemented by mobile assets when and where needed, to receive and relay telemetry signals from flight vehicles to range control centers and user locations.

- Communications Architecture: A Global Range Communication System provides a seamless integration of ground networks, satellites, and mobile assets forming a Global Information Grid (GIG) that provides continuous operation and high data rate capacity for local and external ranges and customers. The system will support voice, video, and data transfer at any frequency, anywhere, at any rate, any time and is intended to provide a secure and reliable high-quality Quality of Service (QoS). Such a robust, global communication system capability enables automated system health monitoring on flight vehicles and range systems, remote repair and configuration, and always-available continuous range operation (requiring no reconfiguration or turnaround time between operations) with sufficient capacity and routing alternatives to support multiple range functions and missions simultaneously.

- Range Command and Control Systems: In the far-term, range command and control systems include autonomous capabilities as appropriate, while relying on a distributed virtual, self-organizing network to provide improved interoperability, responsiveness, and flexibility in distributing command and control data to and from systems that still require some interaction.

- Decision Making Support: Future ranges with global coverage benefit from centralized "range decision authority" for real-time operations. Enabling such an approach requires improved modeling and simulation capabilities to evaluate alternative courses of action as well as more sophisticated information fusion and display capabilities to enable decision makers to rapidly comprehend, assess, understand, and act on real-time situational awareness.

- Planning, Scheduling, and Coordination of Assets: Future space launch and test ranges will benefit from automatic scheduling and coordination of range assets nationwide or even worldwide. Such a capability relies on a national priority process to develop nationwide range schedules involving multiple users, using a consistent process no matter where the launch or flight originates. The vision for this area is to be able to schedule and coordinate use of range assets as robustly and routinely as the FAA provides air traffic control today. The emerging idea is that a knowledge-based intelligent scheduling system - with a "Turbo-Tax" style user interface - will be deployed to assist the user during this phase of its mission. Knowledge of the internet of the launch site or its processes is not a necessity.

- Weather Measurement and Forecasting: In the long term, technology transition units will bring centralized weather system hubs and forecasting centers to all U.S. spaceports and ranges to substantially enhance situational awareness.

ADVANTAGES OF THE FUTURE RANGE VISION

The ARTWG's vision of the ideal range for the far-term future (i.e., 25 years hence) has a variety of desirable characteristics. Based in part on the types of missions future space launch and test ranges will likely be required to support, the ARTWG concluded that the following characteristics are desirable. The future range architecture as envisioned by the ARTWG would addresses the following seven desirable characteristics and provides substantial advantages over today's ground-based, fixed-location range architectures.

1. Reliable, Available, Operable, and Maintainable

- Sufficient to ensure public safety protection within prescribed levels. Minimize risk, controlling to at least required levels, to people, property, and health as a result of all range-supported activities and operations. Ensure capability to command and control flight vehicles to abort, maneuver, or self-destruct in the event the vehicle is outside its preplanned safety corridor, posing a safety hazard to people or property. (This may include autonomous systems aboard flight vehicles.) Ensure ability to prevent potentially hazardous operations in the event of loss of range safety-critical systems or violations of mandatory range safety criteria. Ensure safety through coordination and control of hazardous ground and flight operations among multiple range users, including monitoring and control of access to hazardous land, sea, and airspace areas, and access to information to avoid in-space collisions during range-supported launch and flight test activities.

- Robust architecture. Enable incremental transition from current and planned range architecture to next-generation architecture (e.g., spiral development approach).

- Use of commercial off the shelf (COTS) or government off the shelf (GOTS) and standard products, line replaceable units (LRUs), systems and architectures, where applicable.

<u>Reliable, Available, Operable, and Maintainable</u>

In the far-term, future range systems used for tracking and area surveillance would seamlessly interface with the FAA SATMS and provide multiple functions for both safety and security, facilitating rapid coordination of hazardous ground and flight operations among multiple users. More capable and redundant network-centric, self-configuring, self-healing systems for telemetry, command and control, and communications lead to improved reliability, availability, and maintainability by enabling continuous operations without any downtime required between operations for reconfiguration of range assets. Automated scheduling and coordination systems would help to facilitate better availability of range assets for more users, and better weather modeling and prediction systems lead to more efficient operations on future ranges.

2. Adaptable To Fit the Mission

- Easily adapts to new vehicles and payloads (e.g., multilevel security). Able to adapt to and accommodate new or changing requirements or technologies (e.g., by providing expandable capacity).

- Supports Government and commercial operations and multiple spaceports. Technology development plans define a clear path to mature, test, and demonstrate the required new technologies.

- Supports T&E and development. Support T&E missions with collection, processing, and distribution of more types of data than are available from today's ranges (e.g., tracking multiple noncooperative objects, post-intercept characterization, wideband imaging).

- Supports launching and landing at different sites. Minimize requirements for developing new technologies though new approaches require demonstrations before pursuing certification for use in support of range operations.

<u>Adaptable to Fit the Mission</u>

More widespread use of GPS and on-board inertial systems as primary sources of metric tracking data improves interoperability across flight vehicles and ranges. Relying primarily on satellites for telemetry and commanding helps to expand geographic coverage to a global scale. Supplementing such capabilities with deployable mobile assets when and where needed further enables the ranges to adapt to meet specific mission support requirements. In the far-term, a distributed command and control system including autonomous systems as appropriate, provides interoperability, responsiveness, and flexibility. A network-centric communications architecture taking advantage of the planned Global Information Grid removes constraints associated with frequency spectrum, data rate, routing, and access. Improved scheduling systems enable automatic scheduling of range assets nationwide or even worldwide, when a flight operation is scheduled.

3. Flexibility and Capacity

- Range volume opens and closes to provide capability for when and where needed - dynamically reconfigurable. Support projected workload and mission needs by providing the required range support functions at the required locations and times (i.e., sufficient reliability and availability of range support assets, systems, and functions).

- Responsive flight analysis, flight plan approval, cleared Range available, and other range preparations for short-notice, quick-turnaround launches/landings (e.g., missions that are oriented for science, defense, or safety reasons).

- Able to support concurrent operations including efficient, low-cost support for space launch missions while also supporting more stressing and varied T&E missions. Minimize technical risk, as a contributor to cost and/or schedule risks.

- Increased throughput (operations tempo). Able to support higher operations tempo than today's ranges with more responsive flight safety analysis, flight plan approvals, range preparations, area clearance, automated control, remote asset configuration, asset monitoring, etc., to support short-notice call-up missions (i.e., within hours).

<u>Flexibility and Capacity</u>

Space-based and dispersed, mobile, high-altitude airborne range assets enable future ranges to support multiple concurrent prelaunch and flight test activities. Centralized control and automatic configuration using self-healing systems enable ranges to support a higher operations tempo. A robust communication network using the Global Information Grid helps eliminate range turnaround time and enables continuous availability. Automatic scheduling allows flight operations to be scheduled anywhere on a global range as needed. More accurate and precise weather modeling, measurement, and prediction systems improve forecasting, reduce the frequency of weather scrubs, and increase range throughput and capacity.

4. Integrated With Other Systems

- Shares/passes off data (adheres to approved standards) between ranges and spaceports and off-site customer locations. Support data rates and throughput capacities sufficient to meet mission requirements. Support data latency and diverse routing requirements to ensure timely and reliable distribution, processing, and display of voice, video, and data at range control and user facilities.

- Supports launch and landing from new locations from throughout the United States. Minimize potential cost growth to complete development of future range architecture that will be required to evolve to meet needs associated with RLVs.

- Local volumes open and close with information to support global management.

- Seamlessly integrated with National Airspace Systems (NAS) - (multimodal transportation system).

<u>Integrated With Other Systems</u>

Future tracking systems based primarily on GPS and on-board inertial navigation systems interface with the FAA's planned SATMS. The integration of command and telemetry systems into a robust two-way communication link is designed to support data rates and throughput capacities sufficient to meet next-generation mission requirements. Future developments in decision making support and planning, scheduling, and coordination of assets promise to enable range users and range service providers to access and interact with a common integrated operating picture of a nationwide or global network of ranges using enhanced human interfaces that could include 3-D immersion environments. Communication network improvements, including interface to the Global Information Grid, enhance interoperability.

5. Economical

- Optimizes downrange assets.

- Minimizes permanent fixtures (evolution to a virtual range environment).

- Minimizes operations costs [e.g., low costs for idle range time (no marching army to feed)]. Sufficiently lower operating cost relative to current ranges (as modernized) to justify investment to develop the next-generation range architecture (i.e., acceptable life cycle cost).

- Differing user fees for peak demand time versus off-hour launching and landing slots. Provide adaptability and flexibility in accommodating variations in range workload.

- Encourages standardization of services.

- Affordable development costs, including integration. Affordable estimated development cost, including integration costs - not just the sum of the individual parts. Acceptable risk and sensitivity to cost, schedule, and technical performance problems (i.e., the required funding profile for development, operations, and sustainment is likely to be acceptable).

Economical

Using satellites and mobile range assets to relay tracking, telemetry, and command data would provide a global capability with minimal permanent fixtures, and sharing such assets with other users would dramatically reduce operations and maintenance costs compared to dedicated and fixed-location range assets. New self-healing command and control systems, together with robust communications systems that utilize remote monitor/repair, health and status, and automatic rerouting to improve operability both increase range availability and reduce costs. Centralizing scheduling and coordination of assets requires standardization on a consistent process, leading to efficiency and lower costs. Centralized weather hubs provide more timely data while reducing the workload of human forecasters by up to 90 percent.

6. Integrated Range System

- Degree of range vehicle control available, simple abort versus remote control modes. Development path toward next-generation range that enhances near-term ability of multiple ranges to cooperate in support of operations requiring larger-scale geographic coverage area than provided by today's ranges.

- Distribution of infrastructure: space based, ground-based, ship-based, vehicle based, etc. (can be distributed, all assets do not have to be in one place or at space port). Provide mid-term ability to cover a hemisphere-scale contiguous region with range instrumentation.

- Encourage open architecture and standard interfaces. Provide far-term ability to provide range coverage to support operations virtually anywhere on earth.

Integrated Range System

The future vision for tracking, surveillance, telemetry, and command and control systems is to integrate them in systems that provide real-time situational awareness of regions of interest worldwide. Integrating command and telemetry streams into a generalized, robust two-way communications link is another example of integration. Range communications using networks like the Global Information Grid provide another example of an integrated approach across multiple ranges and user locations, enhancing interoperability, responsiveness, and flexibility. Automating scheduling and coordination of assets require remote access to a single, integrated database system. Similarly, global range operations are enhanced by a global weather modeling, measurement, and prediction system that enables more timely and reliable forecasts.

7. Customer Friendly

- Streamlines process.

<u>Customer Friendly</u>

In general, automating and integrating range functions across broader geographic areas tend to minimize the number of human interventions required, reduce the number of handoffs needed, and provide adaptable services to satisfy user needs. Moving toward autonomous command and control systems further enhances interoperability, responsiveness, and flexibility for range customers. Advanced communication network architecture also allows ranges to support multiple missions and vehicles simultaneously and still provide high quality of service for range users at a variety of locations, all tied into the Global Information Grid. More automated and centralized scheduling and coordination systems improves the consistency among multiple ranges and allow more timely access to range support.

CAPABILITY AND TECHNOLOGY ROADMAPS

CAPABILITY AND TECHNOLOGY ROADMAPS

The purpose of the ARTWG is to define a national technology strategy to enable development of future space launch and test range capabilities relying primarily on space-based assets, supplemented by mobile (e.g., UAV, HAA) range assets as needed, to meet future mission needs. The ARTWG pursued its purpose by developing GOTCHA charts for each functional area. GOTCHA charts establish performance Goals and Objectives for future range functions, define Technical Challenges, and recommend technical Approaches to meet the challenges by listing technology areas requiring development or demonstrations.

The result of this logical process was that each ARTWG subgroup developed both a capability roadmap to establish performance goals and objectives over time and a technology roadmap to address the technical challenges by identifying (1) the technical approaches, (2) current projects underway, and (3) additional technologies requiring further development to reach the performance goals and objectives. This section presents the capability and technology roadmaps developed by each subgroup through the process of creating, populating, and refining the GOTCHA charts, as summarized in the appendices of this report.

Figure 8 summarizes the top-level goals for range system capabilities over time. For the near-term, the primary focus is on demonstrating the utility and beginning some operational use of existing space-based (e.g., GPS, TDRSS, etc.) and mobile (i.e., UAV and HAA) assets as range instrumentation platforms. For the mid-term, the focus shifts to more integrated operational use of space-based and mobile range assets. For the far-term, the goal is to have 80-90% of range systems on space-based platforms that can be seamlessly augmented when and where needed, with mobile or deployable assets and modernized ground assets at departure and recovery locations.

Another major development theme is to continue improving modeling, simulations, and database systems to enable semiautomation of processes, systems, and functions through the near-term, so they can evolve to semiautonomous capabilities in the mid-term. The far-term goal is to use realistic virtual modeling with intelligent systems and optimized use of autonomous systems for various functions, including on-board flight vehicle systems (if desired) and schedule deconfliction.

A third major development theme is to improve standardization, interoperability, and integration of systems throughout a single spaceport and range that is retrofitted into the National Airspace System (NAS) for the near-term, across multiple spaceports and ranges and integrated into the NAS for the mid-term, and fully integrated across a global range network for the far-term.

Finally, several technical areas of range performance were identified for continuous improvement, including modernizing sensors, optimizing the use of frequency spectrum, and improving quality of voice/video/data communication services at higher data rates.

The ARTWG subgroups used this top-level description of the overall capability and performance goals when describing how the seven technical focus area capabilities should evolve over time.

ARTWG developed a top-level summary of the performance goals over time for future ranges.

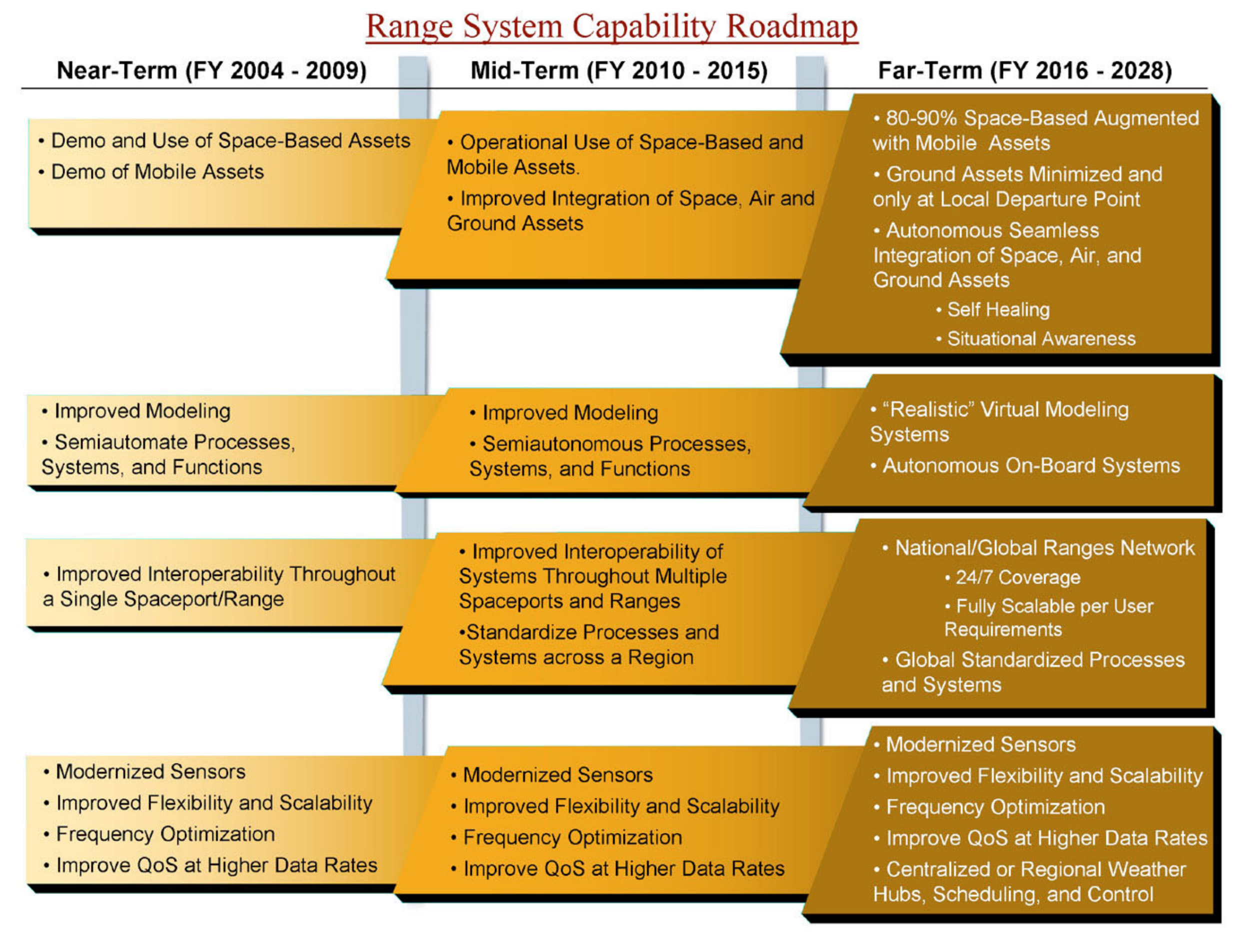


Figure 8 Range Vision: System Capability Goals Over Time

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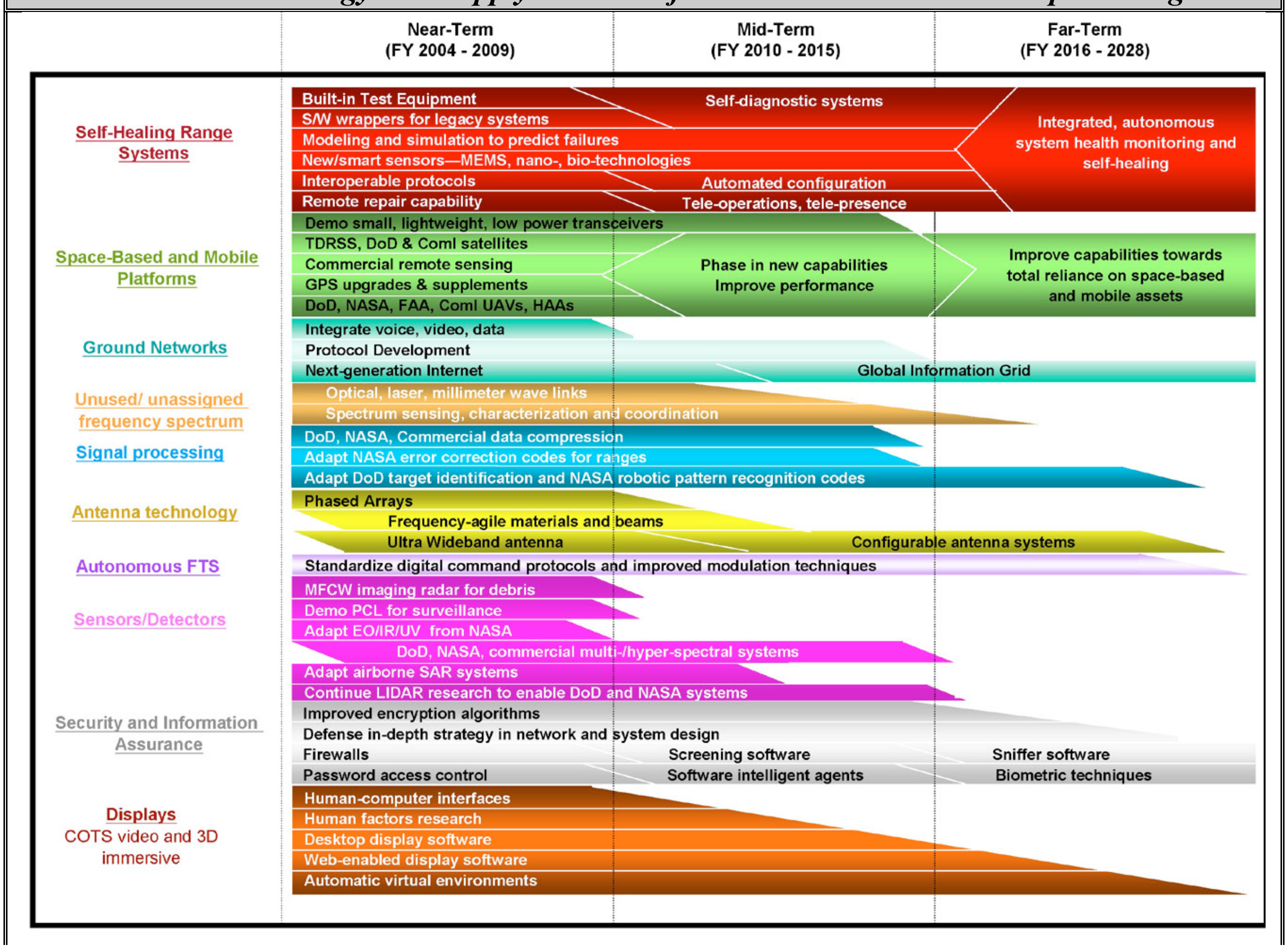
INTEGRATED TECHNOLOGY ROADMAP

INTEGRATED TECHNOLOGY ROADMAP

The integrated technology roadmap presents an overview of the ARTWG's recommended time-phased plan for pursuing specific technologies to address each of the main technology approaches the ARTWG subgroups identified as means of overcoming the technical challenges that stand in the way of achieving the performance goals and objectives they established for each of the range functional areas (see Figure 9).

Individual technology roadmaps for each range functional area addressed by a separate subgroup are depicted in the following sections of this report. Many of these technology areas apply to a variety of the range functional areas, and several cross-cutting elements apply to all of them. The cross-cutting technology areas are depicted and addressed in a separate section of the report, after the sections on the each subgroup's functional area.

The integrated range technology roadmap is based on the individual technology roadmaps each ARTWG subgroup developed for its functional area, plus the cross-cutting technologies that apply across all the functional areas. In addition, several of these technologies apply to several the technology areas apply to several functional areas that make up the range.



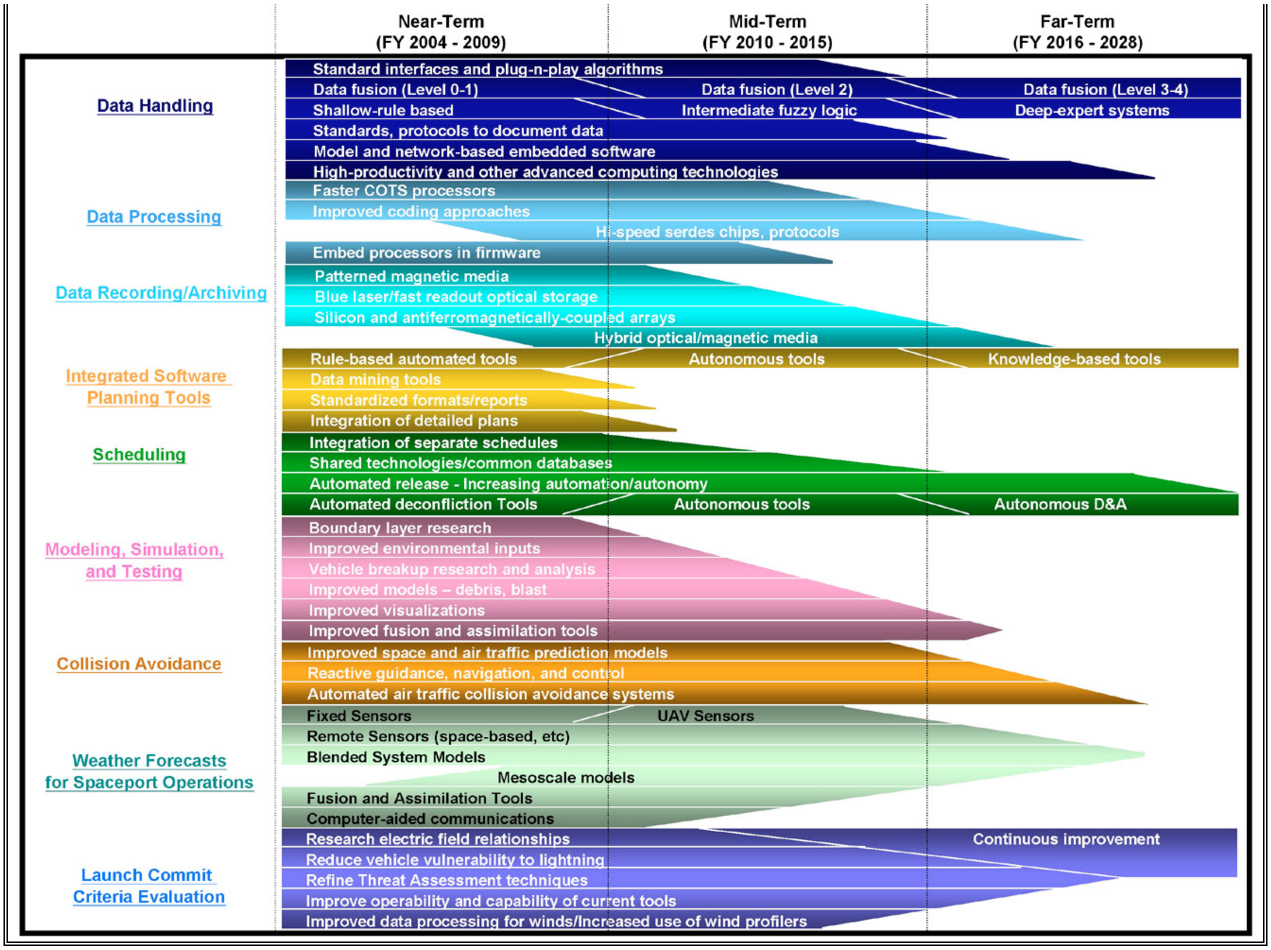


Figure 9 Integrated Technology Roadmap

The roadmap recommends pursuing technologies in the near-term to enable the development of self-healing range systems by starting with built-in test equipment and software wrappers to enable the continued use of legacy systems as new systems are brought on-line at operational ranges. In the mid-term, these technologies can be combined to enable the development of self-diagnostic systems. The roadmap also recommends pursuing parallel near- and mid-term technology improvements in sensor size along with modeling and simulation to better predict component and system failures as means of enhancing the diagnostic capabilities. Near-term technology efforts to improve interoperability and remote repair capabilities can enable evolution in the mid-term to technologies for automated system configuration and teleoperations for repairs. All of these technologies can be combined in the far-term to enable systems with integrated and autonomous health monitoring and self-healing capabilities.

The evolution of space-based and mobile range assets should begin in the near-term by demonstrating the utility and pursuing opportunities for some operational use of existing space-based (e.g., GPS, TDRSS, etc.) and mobile (i.e., UAV and HAA) assets as instrumentation platforms on active ranges. Improvements in the near- to mid-term in light weight, low-power transceivers will be essential to improve the performance of such systems and more integrated operational use of space-based and mobile range assets. For the far-term, the technology focus should be on continuing to improve the capabilities and efficiency of such platforms to enable 80 to 90 percent of range systems to be placed aboard space-based platforms that can be seamlessly augmented when and where needed with mobile or deployable assets.

Technologies to improve ground networks at the ranges include near-term integration of voice, video, and data streams along with development of new protocols and next-generation internet research. These technologies should be further refined, combined, and leveraged to ensure that future range data transport systems are compatible with the Global Information Grid.

A variety of technology options should be examined in the near-term to address the current issues on ranges associated with congested and contested access to frequency spectrum. The near-term focus should address two areas: use of alternative frequencies that are currently unused or unassigned (e.g., optical, laser, millimeter waves) and alternative approaches to the use of spectrum (e.g., spectrum sensing, characterization, and coordination) to enable agile use of spectrum that is assigned but not continuously in use.

Signal processing includes a complementary set of technologies (e.g., data compression, error correction, and target identification/pattern recognition) that could be used in conjunction with the spectrum-related technologies to enable much more efficient use of any and all frequency spectrum in use to provide range functions.

Similarly, antenna technologies should also be pursued in parallel in the near-term to enable exploration and use of alternative approaches to using frequency spectrum. Examples include phased array antenna technologies (e.g., materials, cooling, beam steering), frequency-agile materials to enable use of various frequencies (that also enhances the ability to do frequency hopping as a security measure), and ultra-wideband antenna technologies to explore alternative ways of using frequency spectrum. These technologies can be combined in the mid- to far-term to enhance technologies to enable configurable and adaptable antenna systems.

A far-term capability that truly revolutionizes range operations is the pursuit of an autonomous termination capability for flight vehicles, so the roadmap recommends pursuing technologies to enable standardized digital command protocols and modulation techniques as precursors to enabling autonomous on-board systems.

Meanwhile, space launch and test ranges will certainly continue to rely on sensors and detectors to perform area surveillance for safety and security purposes, while detecting, identifying, and tracking flight vehicles, debris, and toxic vapor clouds and to make weather observations and measurements. Consequently, the roadmap recommends leveraging a variety of near-term efforts in parallel to pursue sensor technologies including multifrequency continuous wave (MFCW) imaging radars, passive coherent locator, electro-optical (EO), infrared (IR) and ultraviolet (UV) sensors, multi-and hyper-spectral sensors, synthetic aperture radar (SAR), and light distance and ranging (LIDAR) (i.e., like radar but with lasers). The less-mature technologies can also be pursued into the mid-term.

One important cross-cutting technology area is security, and information assurance is one important component of it. The roadmap recommends continuous improvements from the near- to far-term in technologies to improve encryption and defense-in-depth strategies. Other near-term focus areas include technologies to enhance firewalls and password protection, leading to mid-term development of screening software and intelligent agents, with the far-term focus on sophisticated technologies for detecting and tracing attempts at system intrusions while relying on biometric techniques to validate the legitimacy of system users.

Next, display technologies should address near- to far-term improvements in human-machine interfaces, human factors, and various technologies to enhance the ability to display information in ways that are both intuitive and meaningful to range system operators and users.

The second half of the integrated technology roadmap begins by addressing three more interrelated technologies: data handling, data processing, and data recording/archiving.

Data handling technologies focus in the near-term first on standard interfaces and plug-and-play algorithms. In parallel, technologies from the near- to far-term focus on enabling increasingly sophisticated levels of data fusion from a variety of disparate sources, starting with rule-based methods, then incorporating fuzzy logic in the mid-term, and expert systems in the far-term. Meanwhile, the near- to mid-term development of standards and protocols to document data and network-based embedded software can be pursued in parallel to enhance the compatibility of data and simplify its combined use. Finally, advanced computing technologies can also be pursued in parallel from the near-term through the far-term to enhance data handling capabilities on ranges. Under the data processing heading, commercial technologies to improve the speed of processors, coding and embedded processors, including serializer-deserializer (serdes) chips and associated protocols, can be leveraged to enhance range capabilities. Similarly, commercial efforts to improve data recording and archiving technologies (e.g., magnetic, optical, and hybrid arrays) can also be leveraged for use on the ranges.

To improve the efficiency of space launch and test ranges to plan and schedule activities, enabling centralized control of more complex and frequent global operations, various integrated software planning and scheduling technologies can be leveraged from the commercial sector. These include increasingly sophisticated automated and autonomous tools using rule- and knowledge-based algorithms, data mining techniques, and methods of standardization and integration to enable sharing of databases and automation of scheduling functions, including deconfliction.

Technologies to improve modeling and simulation apply to a variety of range functions but focus in large part on safety and weather-related areas, including atmospheric and environmental parameters in combination with the characteristics of leaking or exploding propellants and vehicle breakup. Technologies to improve visualization and integration of modeling outputs should also be pursued to take full advantage of the increasingly capable models.

Similarly, three technologies must be developed together to enable enhancements in collision avoidance: increasingly sophisticated predictive models for air and space traffic, adaptive guidance/navigation/control technologies that can respond to avoid collisions, and automated systems to assist in collision avoidance.

Finally, a variety of technologies can be pursued in the near- to far-term to enhance the ability of space launch and test ranges to measure and forecast weather conditions, including lightning, to enhance the safety and efficiency of operations. These include improved sensor technologies, first on the ground and later as instruments to be carried on mobile airborne and space-based platforms, improved models to take multiple conditions and phenomena into account in modeling, and forecasting regional (or mesoscale) weather patterns. Communicating the inputs and results of these improved models also requires improvements in technologies for data assimilation and fusion, combined with computerized output generation and communication.

As a final note, many of the technology areas identified by the subgroups and depicted on the integrated technology roadmap overlap with other areas besides space launch and test ranges. This overlap creates possibilities for synergy and collaboration to advocate, develop, and demonstrate technologies with a variety of applications, both on and outside ranges. In addition, several of the technology areas can be pursued and used together to produce greater positive effects.

SUBGROUP CAPABILITY AND TECHNOLOGY ROADMAPS

SUBGROUP CAPABILITY AND TECHNOLOGY ROADMAPS

This section describes the following products developed by each of the seven ARTWG subgroups:

- Capability Roadmaps - providing more specific goals over time and quantifiable performance objectives for each of the subfunctions that makes up the range function.

- Technical challenges associated with meeting the specific performance goals on the capability roadmaps.

- Technical approaches that address each of the technical challenges.

- Technology development and demonstration projects currently underway to address each technical approach, representing opportunities for synergy with other missions and organizations.

- Technology Roadmaps to illustrate the proposed development path toward enabling the development and demonstration of technologies and systems to meet the capability goals.

These products were developed as a result of intensive effort by each subgroup. Each subgroup consisted of subject matter experts from across the country, working together on an ad hoc and voluntary basis, under the direction of the subgroup co-chairs and the ARTWG leadership. Through facilitated brainstorming over the course of several months, each subgroup identified desired capabilities over time, performance goals for each functional area, objectives for each subfunction, and technical challenges and approaches for each subfunction. Through the same process, each subgroup identified some examples of applicable current technologies and remaining technical challenges. Technical experts from Booz Allen Hamilton were also engaged under contract to assist in identifying current technology projects being pursued by various organizations, with relevance to the technical approaches identified by the subgroups. A subset of each subgroup also participated in a facilitated mini-retreat to capture the results of these brainstorming activities in a consistent format. Finally, the ARTWG leadership team addressed the areas of overlap among the technology areas identified by the subgroups by sorting them out according to the scope of each subgroup's definition, and in the course of this exercise, identified cross-cutting capabilities and technical approaches that apply across all the range functional areas addressed by the subgroups.

The ARTWG team recognizes that these products can and should be further refined to address inadvertent omissions and developments in current and new technologies being pursued in various Government, commercial, academic, and international environments. It is therefore the intent of the ARTWG to continue pursuing an orderly process over time to evolve and refine these products and produce future updates of the capability and technology roadmaps presented in this section.

TRACKING AND SURVEILLANCE

TRACKING AND SURVEILLANCE

The following top-level capability roadmap (Figure 10) lists the qualitative goals for improved range tracking and surveillance capabilities over time, as previously summarized with the other range functions.

ARTWG envisions automated surveillance capabilities, GPS for metric tracking, and modernized sensors for fixed, deployable, and space-based platforms.

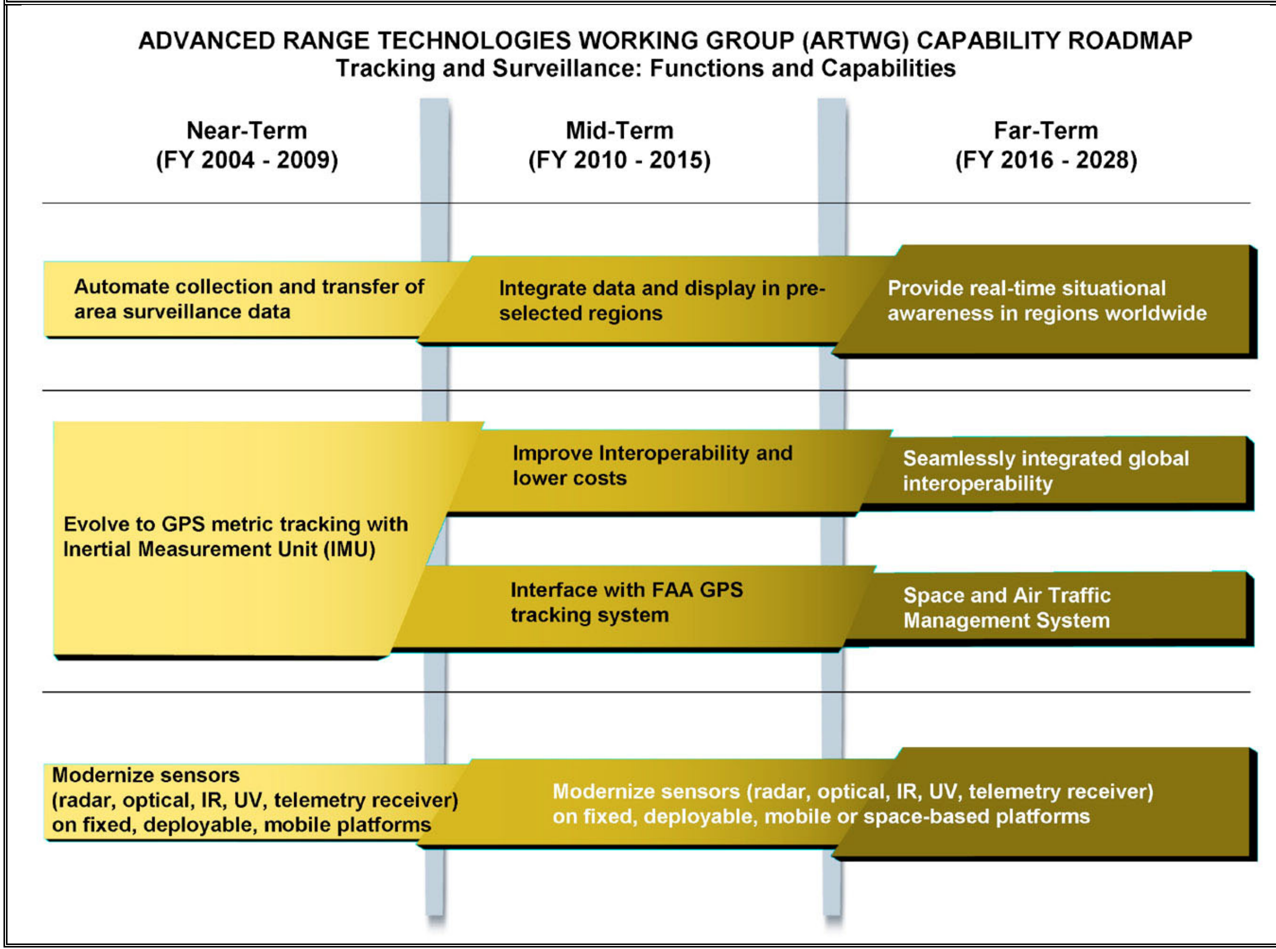


Figure 10 Capability Goals Over Time: Tracking and Surveillance

The following subfunctions and capability goals (Figure 11) were identified by the subgroup as elements of the tracking and surveillance function:

Subfunctions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Far-Term (FY 2016 - 2028)
Conduct Surveillance **1. Detect Objects** ❑ People ❑ Vehicles ❑ Ships ❑ Boats ❑ Aircraft ❑ Rail cars and traffic **2. Identify Objects**	❑ Continue using on-scene sensors for local launch area surveillance ❑ Automate collection of surveillance data from sensors used for mission assurance, safety, and security ❑ Automate transfer of surveillance data ❑ Automate integration, display and update of surveillance data (ships, boats, aircraft) ❑ Integrate area surveillance capabilities for mission assurance, safety, and security	❑ Use dispersed sensors to collect data and provide a regional view to include both local launch area and down range [i.e., along ground trace until orbit injection or no longer terminate (NLT) or no longer endanger (NLE)] ❑ Provide real-time situational awareness within pre-selected regions of interest where hazards could exist near takeoff/landing area and along flight path	❑ Integrate space-based surveillance capabilities ❑ Real-time situational awareness within selectable regions of interest worldwide
Conduct Tracking **1. Detect Objects** **2. Identify Objects** **3. Track Objects** **4. Provide Time-Space Position Information (TSPI)**	❑ Evolve to GPS metric tracking as primary source with IMU data in the telemetry stream ❑ Use modernized sensors (e.g., radar, optical, IR, UV, telemetry receivers) on fixed, deployable, or mobile platforms, as required to collect metric tracking data for specific missions ❑ Automate integration of data from various tracking sources (data fusion) ❑ Increase sample update rate to support ballistic missile intercept testing (i.e., up to 100 samples per second) ❑ Process more tracking data at senor ❑ Improve standardization across flight vehicles and ranges ❑ Lower cost of implementing GPS and IMU metric tracking	❑ Improve interoperability across flight vehicles and ranges ❑ Add modernized sensors on space-based platforms to collect additional metric tracking data for specific missions ❑ Improve information fusion	❑ Global geographic coverage using satellites and mobile range assets to relay tracking data as part of flight vehicle telemetry stream ❑ Improve information fusion

Figure 11 Tracking and Surveillance Subfunctions and Capability Goals Over Time

The following tables further address each subfunction by listing a number of quantifiable performance objectives, associated technical challenges, and technical approaches that could be pursued to achieve the performance objectives. The tables list a number of current projects underway that could enable the development or demonstration of technologies and systems that would address the technical challenges. Following each table is a list of proposed development steps and the technology needs that remain to enable achieving the objectives.

Detecting Objects for Tracking and Surveillance

The first subfunction in conducting area surveillance or tracking of objects of interest on space launch and test ranges is to detect them. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the detection of objects for tracking and area surveillance.

Far-Term Objectives for Detecting Objects for Tracking and Surveillance

Far-Term Objectives (FY 2016-2028)	Technical Challenges	Technical Approaches	Current Technology Under Development
From takeoff or launch, in any potentially hazardous area, along any allowable ground trace or flight path until orbit injection or no longer terminate (NLT) or no longer endanger (NLE): ❑ Detect 100% of ships, boats, aircraft, people, vehicles, and train cars ❑ Detect all objects with >1 square meter cross-sectional area ❑ Detect all major debris (size, number, range) for recovery after vehicle failure or destruction ❑ Detect all major debris that could endanger search and rescue	❑ Adequate coverage of entire geographic area of interest ❑ Terrain obscuration—sensor placement and field of view can be limited by geography (mountains or flat land or water) ❑ Sensitivity of sensors to detect small objects, like individual people or debris ❑ Detecting multiple clustered or dispersed objects ❑ Detecting signals through background clutter, noise; signal loss due to weather, exhaust plume, debris, propellant vapor ❑ Detecting stationary train cars and maintaining data on location and whether any people are aboard ❑ Registration of data from multiple sensor sources ❑ Sensitivity of satellite payloads to radiation for area surveillance ❑ Inability of GPS-based tracking system to detect or track noncooperative objects ❑ Tracking and identification of particulate or toxic vapor dispersal	❑ Automated and autonomous tracking and surveillance systems using dispersed and mobile networks of sensors (e.g., video, acoustic, seismic, railroad track sensors) using multiple phenomenology ❑ Development of more sensitive air- or space-based sensors and tracking algorithms for detecting, tracking, and identifying multiple mobile objects at one time ❑ Signal processing techniques to enhance signal-to-noise ratio and filter data from clutter and to register and fuse sensor data from multiple sources ❑ Passive detection capabilities that do not radiate energy that could interfere with sensitive satellite payloads ❑ Multispectral and hyperspectral sensors to detect/identify vapors ❑ Phased-array radar systems and antennas; multimode antennas to enable use of multiple phenomenology	❑ UAV development by DoD, NASA, and commercial entities ❑ High-altitude airships (HAA) Advanced Concept Technology Demonstrations (ACTDs) by MDA, NORAD, Army, Navy, FAA ❑ NASA Jet Propulsion Lab (JPL) turbo codes for error correction in data streams from spacecraft ❑ Hyperspectral sensors for airborne platforms: NASA JPL AIS-1, 2, AVIRIS ❑ Passive coherent locator ❑ LIDAR systems research ❑ LIDAR Applications Group--NASA LaRC since 1978 ❑ AF Battlelab, Combat Eye pulsed laser LIDAR to see through clouds, smoke, etc. ❑ Phased array antenna development by NASA ❑ Vertically Interconnected Sensor Arrays (VISA) by DARPA/MTO

Mobile Range Platforms

Given the level of interest within DoD, NASA, and the commercial sector in new and innovative applications for unmanned aerial vehicles and high-altitude airships, near-term proposals to pursue technology demonstrations of mobile and dispersed range assets could be met favorably. Here are some examples of specific near-term range demonstrations involving UAVs and HAAs that could be proposed and pursued:

Proposed Development Steps for Mobile Range Platforms
• **Demonstrate the ability of satellites and mobile range platforms to provide more adaptable and flexible range capabilities, as needed for specific launch or test activities**, by demonstrating the ability of space-based or mobile range assets to respond on short notice and supplement existing range functions with specific support capabilities when and where needed.
• **Demonstrate Utility of Existing UAV Capabilities**. Demonstrate the potential utility of existing UAV payload capabilities for range tracking and surveillance or providing video coverage of range-supported operations for postmission engineering analysis.
• **Seek Synergy with MDA, DoD Director of Defense Research and Engineering (DDR&E), Navy, FAA, Coast Guard, and Commercial Entities To Include Range Requirements in HAA ACTDs**. Given the level of interest in airship applications and capabilities within DoD, the Air Force and NASA seek to develop a cooperative relationship with the Missile Defense Agency (MDA), the Director, Defense Research and Engineering (DDR&E) (sponsor of the National Aerospace Initiative to develop and test hypersonic propulsion systems and vehicles), the Navy, FAA, Coast Guard, and commercial entities in sponsoring tests or demonstrations involving such airships on active ranges, using payloads to supplement range tracking or surveillance capabilities, or to demonstrate the ability of such platforms to relay telemetry or command signals between flight test or launch vehicles and ground-based operations control centers.
• **Deployable range assets** should be considered as candidates for technology demonstrations and to supplement range coverage, as needed, particularly in cases where they can be used to test and demonstrate the utility and performance of range systems being developed for use aboard mobile platforms including UAVs and HAAs.

Sensors and Antennas

For years DoD and NASA have been developing and using a variety of sensor technologies to detect objects, including multispectral and hyperspectral sensors, passive coherent locator technology, and LIDAR systems for detection of objects through clouds, fog, etc. DoD and NASA have also pursued various antenna technology projects to improve capabilities. Here are some examples of near-term approaches that could prove useful in improving range area surveillance capabilities.

Proposed Development Steps for Sensors and Antennas
• **Demonstrate the Utility of Airborne Hyperspectral Sensors for Area Surveillance**, including NASA Jet Propulsion Lab's sensors.
• **Demonstrate Passive Coherent Locator Technology for Area Surveillance,** to passively detect and track aircraft in the region surrounding the launch site.
• **Advocate Development and Testing of LIDAR Systems,** including the DARPA, Air Force Battlelab, NASA, and research projects to demonstrate the ability of LIDAR systems to detect objects through clouds, fog, etc.
• **Pursue Phased Array Antenna Technology Development,** to enable simpler solutions for detectors to operate aboard mobile platforms.

Signal Processing

NASA has been pursuing research and technology to address the challenges associated with detecting and identifying features on objects deep in space based on low signal-to-noise ratio data transmissions. Such approaches could also be useful in enabling the development of more efficient area surveillance capabilities.

Proposed Development Steps for Signal Processing
• **Apply NASA JPL Turbo Codes for Error Correction** to enhance the utility of sensor data in detecting and identifying objects in the vicinity of hazardous operations being supported by space launch and test ranges.

Additional Areas for Focused Development

Airship Technologies	Other Technologies for Detecting Objects for Tracking and Surveillance
• Thermal and Gas Pressure Management	• More sensitive air- and space-based sensors for tracking of objects, particularly multiple mobile objects at one time
• Power and Propulsion Systems	• Passive detection capabilities
• Materials Suitability	• LIDAR technologies
• Fabrication Methods and Integration of Structures and Instrumentation	• Weather resistant sensors
• Aerodynamics and Flight Control	• Sensor registration algorithms
• Demonstrating flight to >65,000 feet altitude	• Signal processing technologies for error correction

Identifying Objects for Tracking and Surveillance

The second subfunction in conducting area surveillance or tracking of objects of interest on space launch and test ranges is to identify them. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the identification of objects for tracking and area surveillance.

Far-Term Objectives for Identifying Objects for Tracking and Surveillance

Far-Term Objectives (FY 2016-2028)	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ Positive identification or categorization of all vessels and aircraft along any allowable ground track until orbit injection or no longer terminate (NLT) or no longer endanger (NLE) using autonomous, self-learning systems ❑ Imaging (ability to measure cross-sectional size of object)	❑ Sensor sensitivity, resolution, spectral coverage ❑ Size, weight of optics ❑ Imaging through atmosphere ❑ Jitter induced by motion of mobile platforms ❑ Ground truth, profiles, and comparison data in databases for object and vehicle recognition ❑ Processing speed for pattern recognition and object identification ❑ Today, verification is time consuming, involving human observation aboard aircraft	❑ Dispersed and mobile sensors to provide multiple views of objects of interest over broad areas ❑ Diversity of sensors for multiple phenomenology to aid identification (e.g., EO/IR/UV/imaging radar systems) ❑ Improved sensitivity and signal-to-noise threshold of detectors to make instruments smaller and lighter ❑ Signal processing algorithms ❑ Sensor registration when multiple sensors are used ❑ Database technologies for lookup, rule-based categorization and identification, and learning ❑ Modeling of ground truth data to aid identification ❑ Processing algorithms and pattern recognition software to identify objects of interest ❑ Lighter optical materials ❑ Improve atmospheric correction techniques to improve performance of smaller and lighter instruments ❑ Improve mounts for better performance of sensor systems on mobile platforms	❑ DARPA IXO Eyeball multi-spectral sensor for target identification ❑ DARPA IXO and MDA projects addressing automated target identification (e.g., VIVID pattern recognition project) ❑ Sandia Labs, Intelligent Systems & Robotics, Visual Object Recognition ❑ NASA JPL AIRSAR, SIR-C, X-SAR (synthetic aperture radars) ❑ High-Altitude Intercept Imaging System (HAIIS)—DoD Central Test and Evaluation Investment Program (CTEIP) ❑ Mobile Large Aperture Infrared Telescope (LAIR)—for Navy flight test range, NAWC-WD ❑ HALO-I, II—airborne optical instruments developed for and used by MDA

DoD, NASA, National Labs, and others are pursuing object recognition approaches that could be useful in identifying objects detected during area surveillance on ranges.

Proposed Development Steps To Identify Objects for Tracking and Surveillance

- **Leverage Object Recognition Research** being pursued by DARPA, MDA, Sandia Labs, and others for target identification.
- **Advocate Development of Optical and SAR Capabilities** being pursued for use on ranges in support of missile defense testing and environmental monitoring.

Additional Areas for Focused Development

Other Technologies for Identifying Objects for Tracking and Surveillance
• Modeling of ground truth data to aid identification
• Rule-based database and lookup technology and categorization algorithms
• Data mining within sensor data to aid identification
• Autonomous, self-learning systems including learning databases and neural networks for pattern recognition
• Materials for lighter optics, improved detectors, and improved mounts for optical systems aboard mobile platforms
• Improved optical surface qualities so it is possible for optical instruments to operate closer to diffraction limited resolution with smaller aperture instruments so they are more suitable for use aboard airborne platforms
• Data processing and storage algorithms for massive amounts of hyperspectral data

Tracking Flight Vehicles

Key considerations for tracking flight vehicles include redundancy (number of adequate and independent sources of tracking) and accuracy (+/- x, y, z position; velocity; time). The primary GPS system improvements and low-power transceiver equipment for flight vehicles appear to be the most important technology areas to enable the use of GPS receiver data integrated into the flight vehicle's telemetry stream for metric tracking on space launch and test ranges.

Far-Term Objectives for Tracking Flight Vehicles

Far-Term Objectives (FY 2016-2028)	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ Redundancy (number of adequate and independent sources of tracking) ❑ Perform at accuracy limits of GPS (+/- x, y, z position; velocity; time)	❑ Cost, weight, volume, power constraints associated with GPS receivers aboard flight vehicles ❑ GPS receiver hardware could fail without making its failure known	❑ Atmospheric or space weather can interfere with GPS signals (e.g., coronal mass ejections) ❑ Smaller, lighter, cheaper GPS receivers and transponders ❑ Systems to supplement and strengthen GPS signals ❑ Redundant GPS-based systems for flight vehicles ❑ Integrated health monitoring	❑ Small ELV System for GPS tracking--NASA ❑ Low-Power Transceivers by NASA Goddard Space Flight Center and by ITT ❑ Space-Based Telemetry and Range Safety (STARS) by NASA KSC ❑ Vehicle-Based Independent Tracking Systems ❑ GPS spot-beams and higher power signals ❑ GPS pseudo-lites, differential GPS (DGPS), Local and Wide Area Augmentation System (LAAS and WAAS)

Proposed Development Steps for Tracking Flight Vehicles
• **Advocate and Leverage GPS Improvements** being pursued by DoD and FAA, including higher power signals, spot-beams, and augmentation systems like differential GPS (DGPS), local- and wide-area augmentation (LAAS, WAAS).
• **Develop and Demonstrate Low Power Transceivers for Flight Vehicles** to enable low-cost solutions and more efficient use of on-board weight, volume, and power.

Additional Areas for Focused Development

Other Technologies To Enable GPS-Based Tracking of Flight Vehicles
• Antenna materials and technologies to enable use of lower-power transmitters
• Integrated health monitoring systems to eliminate single point failures
• Systems to ensure that if GPS receiver systems or telemetry systems do fail, their failure mode can be made known to range safety controllers

Tracking and Surveillance Technology Roadmap

The following technology roadmap (Figure 12) displays the major technology areas, with time-phased recommendations regarding particular technologies to pursue in improving the ability of space launch and test ranges to perform the tracking and surveillance functions.

Key technologies for tracking and surveillance include space-based and mobile platforms; GPS upgrades and supplemental systems; lighter, smaller, more sensitive instruments for passive detection in multiple spectral bands; and improved signal processing for error correction and object recognition.

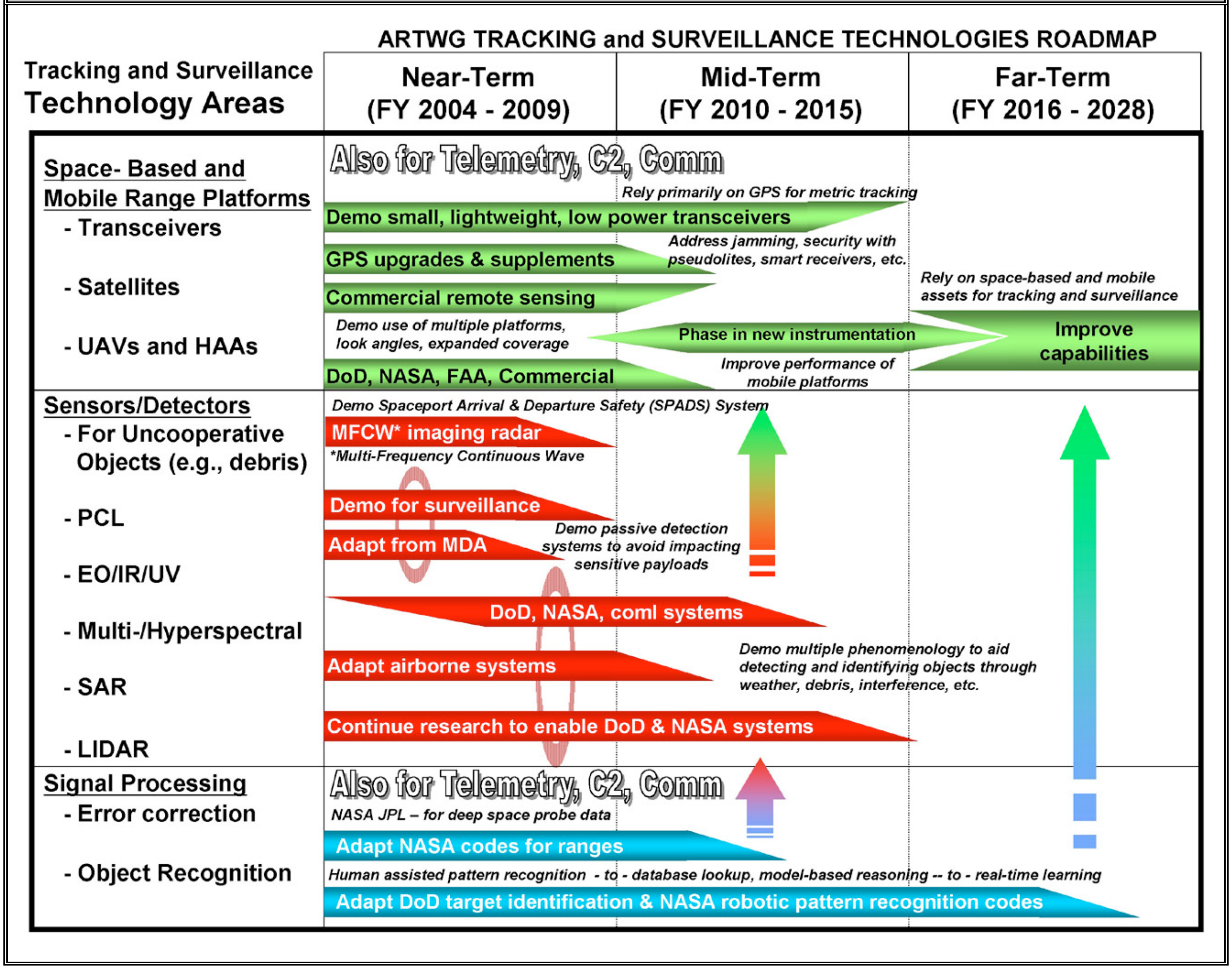


Figure 12 Technology Roadmap for Tracking and Surveillance

TELEMETRY

TELEMETRY

The following top-level capability roadmap (Figure 13) lists the qualitative goals for improved range telemetry capabilities over time, as summarized above with the other range functions.

ARTWG envisions Telemetry capabilities evolving over time to rely more on satellites and deployable mobile platforms for acquiring and relaying telemetry data, and eventually combining the telemetry and command links into one robust two-way connection.

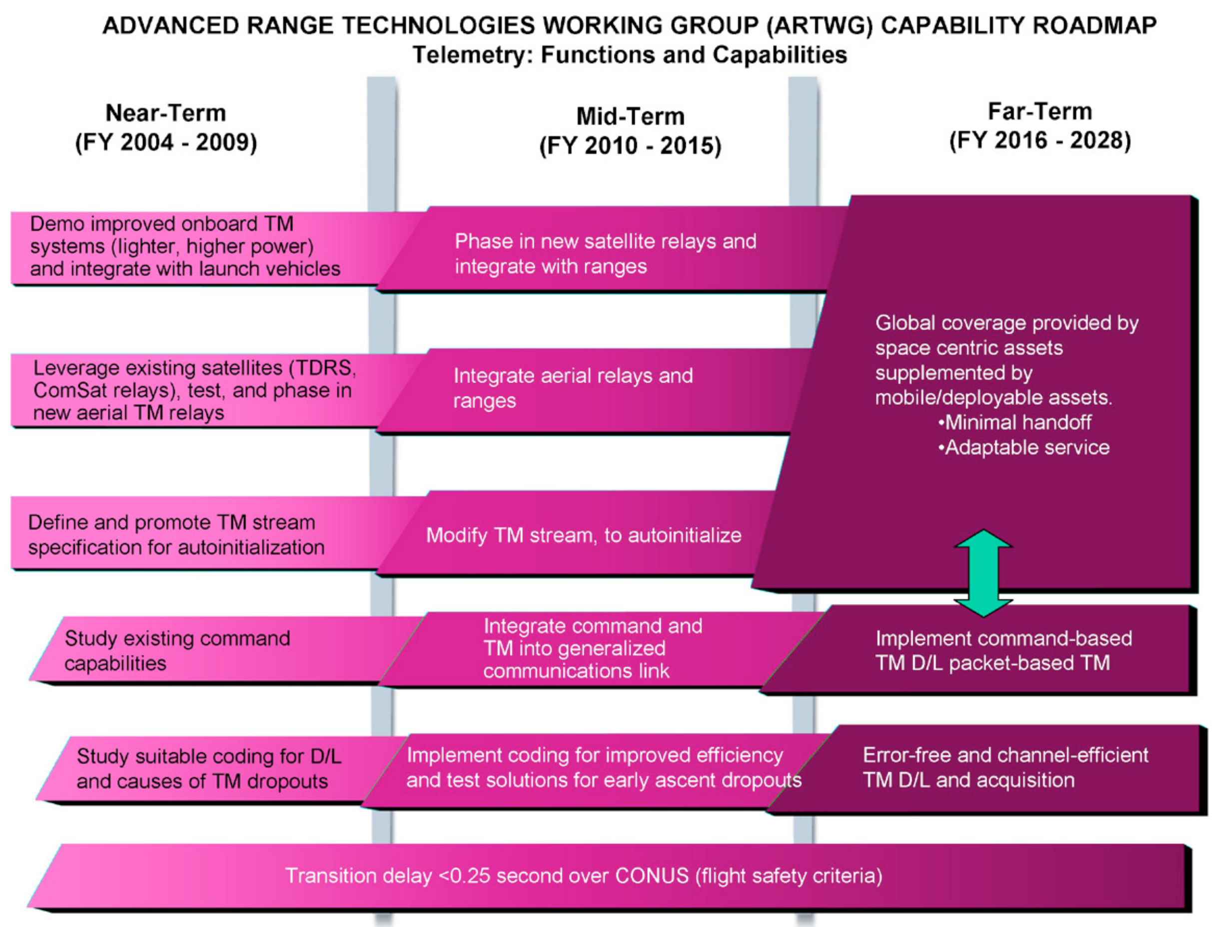


Figure 13 Capability Goals Over Time: Telemetry

The following subfunctions and capability goals (Figure 14) were identified by the subgroup as elements of the telemetry function:

Subfunctions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Far-Term (FY 2016 - 2028)
Acquire Data From Each Flight Vehicle	❑ 10 Mbps, 750Khz ❑ 1 bit/sec/Hz spectral efficiency ❑ Frame loss rate: ~1x10^{-2}	❑ 20 Mbps, no analog ❑ 2 bit/sec/Hz spectral efficiency ❑ Frame loss rate: ~1x10^{-2} ❑ Spectrum agile	❑ 50 Mbps, no analog ❑ 2 bit/sec/Hz spectral efficiency ❑ Frame loss rate: ~1x10^{-3} ❑ Spectrum sharing possible
Process Data 1. Decommutation 2. Scaling 3. Reformatting	❑ <1 hour reconfiguration time ❑ Improved support for special processing ❑ Support two simultaneous major operations	❑ Standardized COTS for interoperability ❑ Routinely support multiple simultaneous major ops	❑ Scalable processing to meet customer needs ❑ National standardization for interoperability ❑ Routinely support multiple simultaneous major ops ❑ Minimal custom equipment.

Figure 14 Range Telemetry Subfunctions and Capability Goals Over Time

The following tables further address each subfunction by listing a number of quantifiable performance objectives, associated technical challenges and technical approaches that could be pursued to achieve the performance objectives. The tables also list a number of current projects underway that could enable the development or demonstration of technologies and systems that would address the technical challenges. Following each table is a list of proposed development steps and the technology needs that remain to enable achieving the objectives.

Acquiring Telemetry Data From Each Flight Vehicle

The first subfunction in dealing with telemetry on space launch and test ranges is to acquire data from each flight vehicle. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address acquiring high-rate telemetry from launch and flight vehicles.

Far-Term Objectives for Acquiring Telemetry Data from Each Flight Vehicle

Far-Term Objectives (FY 2016-2028)	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ 50 Mbps data rate for each telemetry stream (i.e., from each flight vehicle) ❑ 2 bit/sec/Hz spectral efficiency for assigned spectrum ❑ Frame loss rate ~1x10^{-3} ❑ Spectrum sharing capability	❑ Uncertain future access to and assignment of frequency spectrum ❑ Bandwidth demands ❑ Ability to reacquire telemetry stream if lost ❑ Limited satellite capacity for real-time data acquisition ❑ Multipath interference ❑ Plume, plasma, and exhaust attenuation--maintaining link margin at the pad and throughout flight ❑ Integration of Command and Telemetry into a robust two-way link	❑ Use higher frequencies ❑ Use unregulated spectrum (e.g., free space optics, laser links, shared bands) ❑ Alternative approaches to spectrum use (e.g., ultra-wideband) ❑ Signal processing o Multiplexing o Modulation o Data compression o Error correction ❑ Space-based and mobile platforms for telemetry acquisition ❑ Steerable antennas ❑ Millimeter wave transmissions Adaptive optics, free-space optical communications	❑ Low power transceivers (e.g., NASA KSC Small ELV Transmitter, Space-based Telemetry & Range Safety (STARS) by NASA KSC, IRIDIUM & Globalstar flight modem experiments at NASA WFF. ❑ DoD Transformational Communication System and European ARTEMIS satellite—laser links ❑ Programs addressing multipath and unused spectrum (e.g., DARPA's Next-Generation (XG) Communications and commercial programs that may boost the capacity of certain wireless links by 10 to 20 times). ❑ Ultra Wide Band Array Antenna by DARPA/MTO ❑ Tera Hertz Operational Reachback (THOR) by DARPA/ATO ❑ High Performance Computing Systems (HPCS) by DARPA/IPTO to enable rapid, efficient data compression, error correction ❑ Innovative Space-Based Radar Antenna Technology (ISAT) by DARPA/DSO ❑ Steered Agile Beams (STAB) by DARPA/MTO ❑ Reconfigurable Aperture Program (RECAP) by DARPA/SOP Airborne Communications Node (ACN) by DARPA/IXO ❑ Frequency Agile Materials for Electronics (FAME) by DARPA/SPO ❑ Plasma Wave Advanced Receiver (PARX) by NASA GSFC

Mobile Range Platforms

After demonstrating the potential for various types of mobile platforms as range assets, NASA and the Air Force range community should consider conducting a formal Analysis of Alternatives (AOA) to sort through the relative merits associated with the wide variety of possible platforms that could be used to host mobile range assets, including DoD, NASA, and commercial UAVs or airships. Some near-term demonstrations and collaboration efforts that could be pursued to explore the potential of mobile platforms as range assets are explained in the following table.

Proposed Development Steps for Mobile Range Platforms

- **Demonstrate Range Payloads Aboard UAVs or HAAs**. A demonstration requiring some new instrumentation development and integration would showcase the utility of UAVs as platforms to supplement existing range capabilities to provide data relay for tracking, telemetry, and commanding between flight test or launch vehicles and ground-based operations control centers.
- **Advocate the Air Force Flight Test Center's (AFFTC's) Proposed Plan To Develop and Demonstrate Airships as Mobile Range Assets**, a three-phased approach:
  1. Demonstrate utility of a single, manned, leased commercial off-the-shelf airship as a range instrumentation platform with 8- to 12-hour duration on station
  2. Demonstrate ship-to-ship data relay using two airships to provide expanded geographic coverage and duration on station of 3 to 5 days
  3. Develop and test airship for operation at higher altitude and with longer duration (e.g., 90 days)
- **Seek Synergy With NASA and Commercial Entities in Conducting UAV and HAA Demos**. Given the level of interest in UAV applications and capabilities within NASA and the commercial sector, the DoD and NASA range communities could seek cooperative arrangements with appropriate entities to assemble UAV technology demonstrations of interest to both commercial developers and the range community. A logical example could demonstrate the ability of commercial UAVs to provide data relay for telemetry or commanding between flight test or launch vehicles and ground-based operations control centers.
- **Arrange range technology demonstrations in conjunction with active range support for near- to mid-term missile defense tests or hypersonic flight test experiments** as a means of demonstrating the ability of mobile range assets to provide expanded geographic coverage beyond the areas that are currently instrumented for range support, when and where required to support specific missions.

Low Power Transceivers

The DoD and NASA range communities should continue to advocate experiments and demonstrations of various low-power transceivers for use aboard flight vehicles to be tested or operated on ranges. One example is the Low Power Transceiver (LPT) being developed by ITT to provide a 12-channel S-band and L-band receiver and an S-band transmitter in a 5 kilogram, 5-inch x 5-inch x 5-inch package capable of producing a 25-watt signal.

Proposed Development Steps for Low Power Transceivers

- **Demonstrate NASA KSC Space-Based Telemetry and Range Safety (STARS).** STARS is a program to demonstrate space-based telemetry, command and control, and communication relay from mobile platforms. It includes evaluation of various modulation techniques for more efficient use of spectral bandwidth and measurement of data latency for telemetry, command and control, and real-time video.[1]

- **Continue Development of Small ELV Transmitter at NASA KSC.** NASA's Small Expendable Launch Vehicle (ELV) Transmitter Project is using LPT technology to develop a 30-watt telemetry transmitter that will be compatible with TDRSS. This unit has completed preliminary design review. The data rate for the two encodable independent channels is up to 4 Mbps per channel.
- **Advocate Continued Demonstrations of IRIDIUM and Globalstar Flight Modems at NASA Wallops Flight Facility (WFF).** A November 2001 Orion rocket was launched from a Swedish range with a Globalstar flight modem. In this test, the Globalstar call was lost twice, forcing the payload computer to redial the call.[2] Further testing would be useful to determine the limitations and capabilities of such modems for telemetry, command and control, and communication relay.
- **Advocate Flight Demonstrations of Vehicle-Based Independent Tracking System (VBITS).** VBITS is designed to transmit real-time GPS and IMU tracking data from a launch or flight test vehicle to ground receivers or to commercial low Earth orbit (LEO) satellites. It is designed to satisfy RCC 324-01 GPS Requirements. The system is differential GPS compatible and includes a universal patch-antenna system that can be mounted on rockets, missiles, aircraft, and UAV platforms.[3]

Signal Processing

The DoD and NASA range communities should consider monitoring, coordinating, and leveraging among various ongoing government and commercial efforts focused on signal processing to add particular emphasis to the pursuit of techniques that could be used to improve the quality and efficiency of low signal-to-noise transmissions at higher frequencies.

Proposed Development Steps for Signal Processing

- **Sponsor and Coordinate Signal Processing Research and Technology**. Specifically, DoD and NASA may consider it worthwhile to sponsor or coordinate research or technology demonstrations on active ranges to explore the potential applicability of:

  Advanced Equalization Techniques to lower bit error rates

  Advanced Modulation Techniques to make more efficient use of frequency spectrum with improved noise performance

  Advanced Error Correction Techniques (e.g., Turbo codes) to make more efficient use of higher-frequency spectrum for telemetry
- **Seek Synergy With UAV Battlelab Efforts Relating to Data Compression**. The DoD and NASA space launch and test range communities may consider it worthwhile to establish a more interactive and cooperative role with the UAV Battlelab at Eglin Air Force Base, Florida, to explore whether the specific data compression techniques it is developing for UAVs could be applied to make more efficient use of the frequency spectrum used by space launch and test ranges, particularly for high-data-rate telemetry.
- **Leverage Enhanced Bandwidth Efficient Modem Procurement** by U.S. government agencies to provide flexibility between Government and commercial entities, integrating legacy systems with more of an open-systems architecture (i.e., backward compatibility), while also incorporating higher data rate and improved throughput capabilities.

Enable Use of Higher Frequencies on Dynamic Vehicles

Expanding research and development work on high-power amplifiers and antenna applications on high-performance aircraft and launch vehicles would enable future space launch and test ranges to make use of higher frequencies for telemetry.

Proposed Development Steps To Enable Use of Higher Frequencies on Dynamic Vehicles

- **Expand Wide Bandgap Semiconductors Research for High Frequency Power Amplifiers**. DoD or NASA may wish to consider the potential value of participating in or expanding the Naval Research Lab's materials research relating to wide bandgap semiconductors to enable the development of power amplifiers suitable for use at higher frequencies for range applications.
- **Adapt Hardware for High-Dynamic Vehicles**. It may also be worthwhile for the DoD and NASA range communities to consider experiments or development work to adapt COTS phased array aircraft antenna and signal processing equipment currently in use to determine if it can maintain a robust two-way data link during high-dynamic and anomalous flight of launch and flight test vehicles.

Additional Areas for Focused Development

Other Technologies To Enable Acquisition of High Data Rate Telemetry
• Low-power and compact autonomous, self-reacting spectrum-sensing characterization and coordination technologies, for new ways to use assigned or unassigned frequency spectrum
• Laser and free space optical communication capabilities, including adaptive optics to overcome atmospheric variations and scintillation
• Revolutionary antenna materials and technology to enable use of low-power transmitters, improved antenna gain technologies
• Data compression, error detection/correction to address bandwidth constraints and higher data rate requirements
• Antennas in space, sensing from space or mobile platforms to overcome interference from rocket exhaust and plume - UAVs and HAAs with lower costs, higher reliability, and longer endurance with over-the-horizon connectivity between multiple sensors to provide multiple transmission paths, including paths upward away from the exhaust plume
• Millimeter wave transmissions that are less sensitive to exhaust plume interference

Processing Telemetry Data

The second telemetry subfunction is to process the data in the telemetry stream. Telemetry processing typically includes decommutation (i.e., extracting individual parameters or measurements from a formatted telemetry stream), scaling (i.e., converting raw measurements into engineering units), and reformatting for distribution and display. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the ability to process telemetry data.

Far-Term Objectives for Processing Telemetry Data

Far-Term Objectives (FY 2016-2028)	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ Scalable processing to meet customer needs ❑ National standardization for interoperability ❑ Routinely support multiple simultaneous major ops	❑ Processing speed to extract data with allowable latency ❑ Fail-safe multimode processing ❑ Doppler effect ❑ Configuration management for standard and user-defined data formats and processing algorithms ❑ Test and verification of processing algorithms ❑ TM System Initializaton	❑ Faster processors (e.g., using SiGe and CMOS semiconductors) ❑ Hardened chips for space-based processing ❑ High-speed serializer/ deserializer chips and protocols (e.g., OC-768 for 40 Gbps) ❑ Embed processing algorithms in reprogrammable firmware ❑ Improve telemetry processing algorithms ❑ Standard high-level language for data processing without user writing unique code ❑ Built-in test, self-diagnostic systems ❑ Standard format for telemetry data description (e.g., Telemetry Attributes Transfer Standard (TMATS) or extensible Markup Language (XML)	❑ Chip-Scale Wavelength Division Multiplexing (CS-WDM) by DARPA/MTO ❑ Fast Readout Optical Storage Technology (FROST) by Call/Recall Inc. and DARPA ❑ Networked Embedded Software Technology (NEST) by DARPA/IXO ❑ High Performance Computing Systems (HPCS) by DARPA/IPTO ❑ COTS products that translate XML data for display on personal digital assistants (PDAs)

In devising and constructing range technology or capability demonstrations involving telemetry and commanding from space-based and/or mobile platforms, DoD and NASA should consider incorporating packetized data, protocols, and architectures that are being used in state-of-the-art computer networks today and proposed for use on advanced networks in the future.

Proposed Development Steps for Processing Telemetry Data

- **Pursue Synergy With DARPA Projects To Enable Faster Processing**, including projects addressing protocols, access to stored data, software and firmware, and novel approaches to processing.
- **Leverage High-Speed Processor Development,** including semiconductor materials research, standards, languages, and protocol development.

Additional Areas for Focused Development

Other Technologies To Enable Acquisition of High Data Rate Telemetry
• Improved data latency technologies like third-generation (3G) wireless technology
• Wavelength division multiplexing (WDM) component and network technologies
• Common network protocols for data sharing and communication
• Autonomous, self-learning/configuring/repairing/maintaining equipment
• Learning databases
• Standardized data processing and storage technologies

Telemetry Technology Roadmap

The following technology roadmap (Figure 15) displays the major technology areas, with time-phased recommendations regarding particular technologies to pursue in improving the ability of space launch and test ranges to acquire high data rate telemetry.

Key technologies for telemetry include space-based and mobile platforms; improved signal processing for data compression and error correction; enabling use of unregulated, unassigned, or unused frequency spectrum; antenna technologies; longer-lived, more efficient optical and magnetic storage media; and advanced data handling.

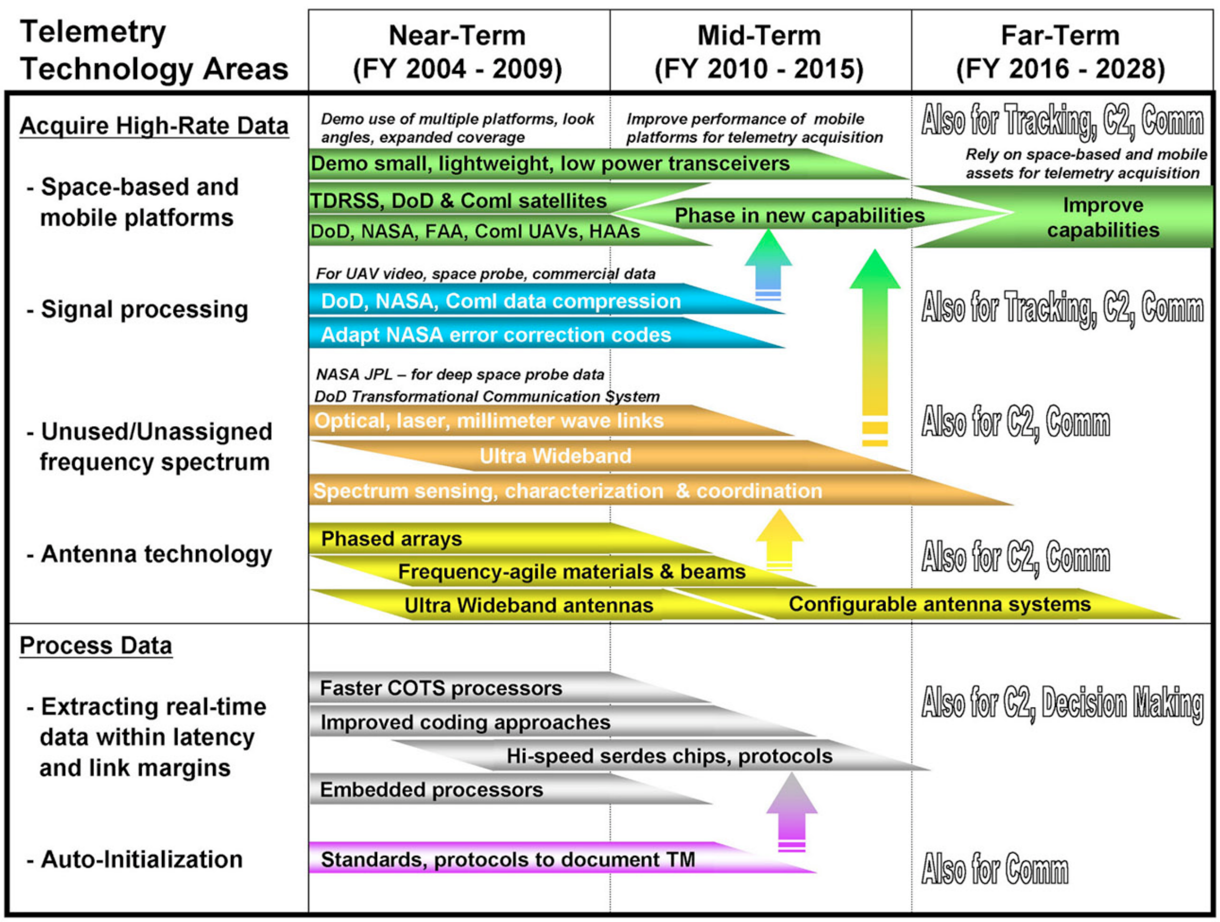


Figure 15 Technology Roadmap for Telemetry

COMMUNICATION ARCHITECTURE

COMMUNICATION ARCHITECTURE

The following top-level capability roadmap (Figure 16) lists the qualitative goals for improved range communication architecture performance over time, as previously summarized with the other range functions.

ARTWG envisions Communication capabilities evolving over time to result in global network interconnectivity with voice, video, and data distribution through high speed ground networks, satellites, and mobile range assets, delivering a high quality of service.

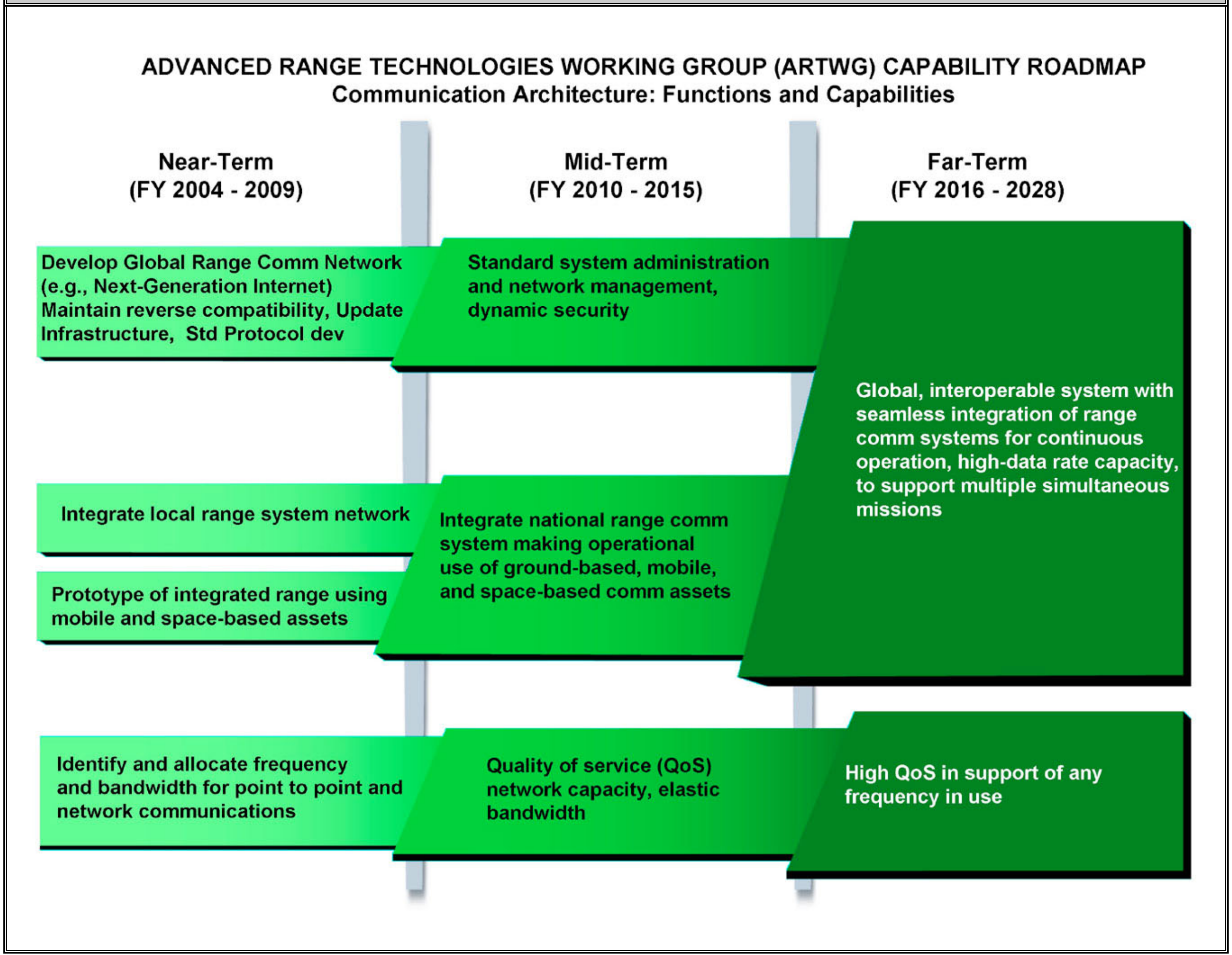


Figure 16 Capability Goals Over Time: Communication Architecture

The result: A Global Range Communication System with seamless integration of networks, satellites, and mobile range assets for continuous operation and high-data rate capacity.

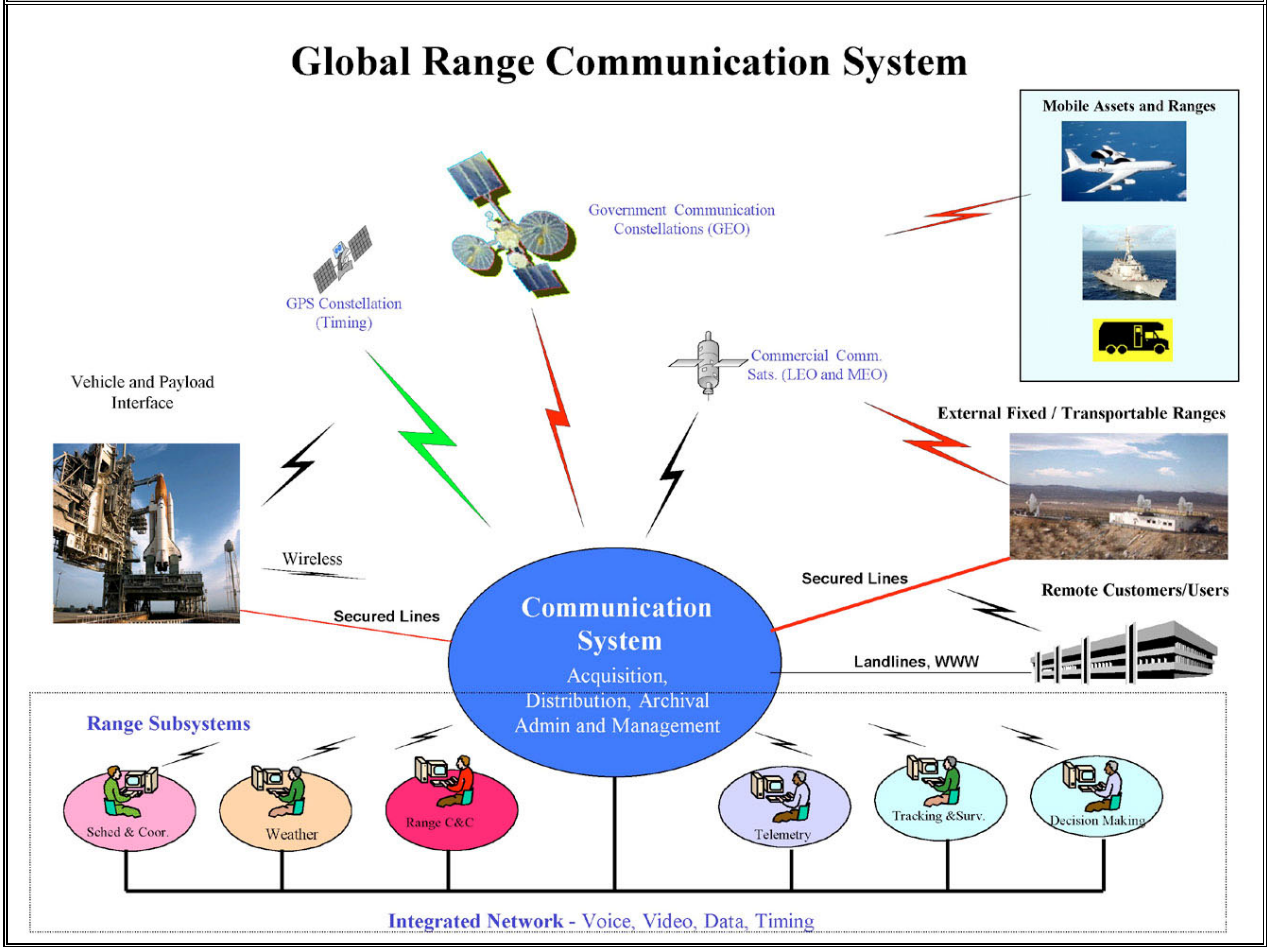


Figure 17 Global Range Communication System

The following subfunctions and capability goals (see Figure 18) were identified by the subgroup as elements of the range communication architecture function. Security is a cross-cutting function that affects all range subsystems. Security affecting communications, information technology, networks, data storage, intrusion detection and jamming are addressed under the Cross-Cutting Architecture.

Subfunction 1. Distribute Voice, Video, Data, and Timing			
Elements	**Near-Term (FY 2004 - 2009)**	**Mid-Term (FY 2010 - 2015)**	**Far-Term (FY 2016 - 2028)**
Coverage Area	❑ Enhance and integrate local range network, interconnected among communication ranges in a region ❑ Demonstrate and use commercial and Government satellites and mobile assets for range communications	❑ Integrated national range network ❑ Expand use of commercial and Government satellites (e.g., Transformational Communication System [TSC])) and mobile assets for range communications ❑ Develop global coverage capability	❑ Rely on Next-Generation Internet, commercial and Government satellites (e.g., TCS), mobile assets and interface to the GIG for range communication ❑ Scalable coverage when and where needed ❑ Easily configurable and seamless data transfer among ground, space, and mobile systems
Data Sharing	❑ Enhanced local distribution ❑ Protocol Development ❑ Distribute data over Internet using COTS (push) ❑ Data sharing across range ❑ Enhanced network remote distribution ❑ Data to the desk ❑ Limited use of commercial satellite systems for remote customer access over Internet ❑ Local wireless voice, video, and distribution systems (PDA's, laptops, cell phones)	❑ Multicast distribution to local and remote sites ❑ Access data remotely (pull), routinely, securely over Internet ❑ Data sharing across regional network of ranges ❑ Regular-use commercial satellite systems ❑ Nationwide wireless voice, video, and data distribution systems (PDA's, laptops, cell phones)	❑ Data sharing across the national/global range so customers get data where and when they need it (near real time) in media they define (digital media) ❑ Robust global network of interconnected systems ❑ Routine, secure delivery via Internet
Size of Pipeline (Multiple Data Channels)	❑ Phase out of point-to-point distribution in favor of network approach (e.g., voice and telemetry over IP) ❑ Improve Quality of Service (QoS) ❑ Serial digital video distribution (270 Mb/s) ❑ Convert any analog data system to digital ❑ Maintain independent capability for range safety requirements ❑ Integrate voice, video, data, timing streams—data fusion	❑ Integrated national range network ❑ Further improve QoS ❑ All data types converted to digital for transmission and distribution ❑ High-definition video distribution (360 Mb/s) ❑ Use digital compression techniques to make more efficient use of bandwidth ❑ Maintain independence and capability for safety, if required	❑ Reflect the user's needs—scalable capacity available when and where needed ❑ Further improve QoS ❑ Complete integration of voice, video, data and timing for distribution across the global network (GIG) ❑ Maintain independence and capability for safety, if required
Data Rate (per Channel)	❑ 100 Mbps (space) ❑ 100 Mbps (mobile) ❑ 10 Gbps (ground)	❑ 10,000 Mbps (space) ❑ 10,000 Mbps (mobile) ❑ 100 Gbps (ground)	❑ 40,000 Mbps (space) ❑ 40,000 Mbps (mobile) ❑ Tera-bits/second (ground)
Spectral Efficiency/ Frequency Use	❑ Spectral efficiency (SE): SE = 3 bps/Hz ❑ Increase efficiency of frequency usage within a range ❑ R-spread spectrum, frequency hopping, etc. ❑ Semiautomated dynamic allocation of bandwidth	❑ SE > 3bps/Hz ❑ Spectrum sharing within a region ❑ Automated dynamic/scalable bandwidth: automatic bandwidth allocated based on data type	❑ SE > 3 bps/Hz ❑ Optimized utilization of the spectrum ❑ Autonomously dynamic/scalable bandwidth: automatic bandwidth allocated based on data type

Subfunction 2. Record and Archive Data			
Elements	**Near-Term (FY 2004 - 2009)**	**Mid-Term (FY 2010 - 2015)**	**Far-Term (FY 2016 - 2028)**
Data Volume	❑ 5 Gbytes/test	❑ >15 Gbytes/test	❑ > 25 Gbytes/test
Compatibility	❑ Medium ❑ Development and adaptation of format standards ❑ Standardized digital formats ❑ Flexibility to handle different formats and user preference ❑ Standardize on a media, use commercially viable	❑ High ❑ Enhanced format standards ❑ Flexible data exchange between range and users ❑ Range and user able to record all needed streams in real-time	❑ Transparent resolution of compatibility issues between systems and networks ❑ Common media are supported across ranges ❑ Media independence
Data Access	❑ Semiautomated process to access data ❑ Common data retrieval systems ❑ Network and web-based access to data ❑ Operational voice, video, and time stamping	❑ Automated process to access data ❑ Data mine to user needs ❑ Enhanced web-based and network access to data ❑ Traditional voice, video, and stamping	❑ Users can navigate with sufficient controls; fully automated, remote access ❑ All recorded data with stampings (meta-data)
Media Transition	❑ Ability to continually migrate data to newer media ❑ Preserve previous analog data in digital format ❑ Use commercial standards and formats	❑ Ability to continually migrate data to newer media ❑ Continued use of commercial standards and formats	❑ Ability to continually migrate data to newer media ❑ Continued use of commercial standards and formats
Post-Op Support/ Analysis	❑ Enhanced automated data collection and analysis within the local range ❑ Collect and provide range performance data for post-operation analysis, to include reliability/maintainability analysis data ❑ Automated analysis of range performance ❑ Record and store on-line all inputs, outputs, and operator system interaction during launch and test operations ❑ Electronically archive all or selected recordings in standardized and commonly used formats, including the ability to store, index, and retrieve	❑ User conducts analysis as needed—data is available for user ❑ Enhanced automated data collection and analysis within the region	❑ Routine analysis (e.g., informed vehicle monitoring or mission operations) ❑ Automatic data collection and analysis

Subfunction 3. Network Administration and Management			
Elements	**Near-Term (FY 2004 - 2009)**	**Mid-Term (FY 2010 - 2015)**	**Far-Term (FY 2016 - 2028)**
Administration and Management	❑ Automatic management of local networks ❑ Self-organizing networks ❑ Implementation of QoS	❑ Automatic management of the national network—priorities ❑ Enhanced self-organizing networks ❑ Enhanced QoS	❑ Policy-based ❑ End-to-end QoS ❑ Automatically manage the global network—priorities ❑ Integrated with the GIG
Distribute Real-Time Data	❑ Leverage public networks	❑ Routine, safe delivery via Internet ❑ Multicasting	❑ Flexible network ❑ Routine, safe delivery via Internet
Security	❑ Increased security ❑ Standardized authentication ❑ Encryption of raw telemetry (TM)	❑ Encryption of TM, strong authentication, and remote displays	❑ Encryption of TM, strong authentication, and remote displays

Figure 18 Communication Architecture Subfunctions and Capability Goals Over Time

The following tables further address each subfunction by listing a number of quantifiable performance objectives, perceived associated technical challenges and technical approaches that could be pursued to achieve the performance objectives. The tables also list a number of current projects underway that could enable the development or demonstration of technologies and systems that address the technical challenges. Following each table is a list of proposed development steps and the technology needs that remain to enable achieving the objectives. The list is not exhaustive and more study is required.

<u>Distribute Voice, Video, Data, Timing</u>

The goal is to provide a global range communication system relying primarily on a Global Information Grid for voice, video, data, and remote distribution, through high-speed ground networks, supplemented with commercial and Government satellites and mobile assets.

Far-Term Objectives for Distributing Voice, Video, Data, Timing			
Far-Term Objectives (FY 2016-2028)	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Global Coverage Area	❑ Distance between transmitter and receiver drives need for transmitter power aboard satellites, flight vehicles, mobile range assets ❑ Antennas for satellites, flight vehicles, and mobile range assets ❑ Suitable satellites and mobile platforms for range comm. relay ❑ Cross-links between satellites and/or mobile assets ❑ Communicating through plasma during ascent (rocket exhaust plume) and reentry	❑ On-board power for transceivers (e.g., fuel cells, solar power, batteries, flywheels) ❑ Lighter, smaller, more efficient power amplifiers and transmitters ❑ Antenna technologies (e.g., phased array, steerable beam, improved surface tolerance to enable use of higher frequencies, etc.) ❑ Utilization of Government and commercial satellites, UAVs or HAAs, and other mobile platforms for range communication ❑ Optical and laser communication	❑ Hydrogen Storage for Fuel Cells at NASA LaRC ❑ Solar Power Generation element of the Space Solar Power Exploratory Research and Technology (SERT) activity at NASA/JPL ❑ Polymer ion battery by Space Info. Labs ❑ Nanoconverters at NASA JPL ❑ Space-based Telemetry and Range Safety (STARS) – Low Powered Transceiver by NASA KSC ❑ IRIDIUM and Globalstar flight modem experiments at NASA WFF ❑ Flexible digital payloads for satellites (e.g., Thuraya, Spaceway) with reconfigurable phased array antennas, digital beamforming, digitally programmable channel assignments. ❑ Multibeam Antennas advanced phased arrays by NASA GRC ❑ Next-generation TDRSS ❑ Advanced Extra-High Frequency (AEHF) Satellite Communication (SATCOM) ❑ Global Multimission Support Platform (GMSP)—adding a comm. relay capability to the GPS constellation (MITRE, SMC/XR) ❑ Multiuse UAVs (e.g., area surveillance, telemetry collection, comm. relay, optical tracking and identification, etc.) ❑ HAAs and UAVs for testing of space-based capabilities such as laser comm. links. ❑ Waveguide Laser for GPS spot beam technology ❑ DoD's TCS – Optical Laser Link technology ❑ DARPA efforts to quickly sense and respond to frequencies already in use as a means of minimizing interference and making more efficient use of spectrum. ❑ Spot beam technology ❑ Personal Communication Network (PCN) point-to-point radios
❑ Data Sharing	❑ High Bandwidth Networks ❑ Integration of various networks and data types (voice, video, data, timing) ❑ Integration of satellite and mobile systems into a seamless communications system ❑ Multiple ranges and user locations	❑ Advanced networks and software algorithms ❑ Lossless, low latency compression techniques (voice, video, data, timing) ❑ Space-rated and commercial network interfaces ❑ Advance protocols (next-generation internet [NGI], internet protocol [IP] in space, mobile IP, voice-over internet protocol [VOIP]) ❑ Wireless systems	❑ Chip-Scale Wavelength Division Multiplexing (CS-WDM) by DARPA/MTO ❑ VOIP, MPEG-2 ❑ Protocols: IPV6, VOIP, Multi-Protocol Label Switching (MPLS), Generalized Multi-Protocol Label Switching (GMPLS), Interplanetary Internet, Border Gateway Protocol (BGP) ❑ IP in space demonstrated NASA ❑ Interplanetary Internet by NASA JPL ❑ MPLS to enable single, global, scalable, and resilient network backbone ❑ Ultra-Wideband (UWB) research by NASA KSC ❑ Internet II, Next Generation Internet (NGI)

❑ Size of Pipeline (Multiple data channels) ❑ Data rate (per channel) ❑ Spectral Efficiency/ Frequency Use	❑ High data rates (40.000 Mbps—space/mobile, tera-bits/sec-ground) ❑ Scalable bandwidth based on user requirements ❑ Real-time data requirements ❑ Latency (RS data < 500ms, video < 100 ms, voice < 30 ms, data < 1 ms, LEO = 10 ms, MEO = 120 ms, GEO = 250 ms) ❑ Network traffic, collision, and jitter ❑ RF Interference and Doppler effects	❑ Multiplexing, spread spectrum, modulation techniques ❑ Quality of Service (QoS) ❑ Throttleable bandwidth (customized bandwidth) ❑ Data compression ❑ Faster processors and software algorithms ❑ Millimeter waves, UWB, modulation techniques	❑ Wide band-gap semiconductors by Naval Research Laboratory (NRL) to enable higher-frequency amplifiers ❑ High-performance data compression in NASA/GSFC ❑ DoD's Multisensor Command and Control Constellation (MC2C) ❑ Differentiated Services (DIFSERV) ❑ DoD's Joint Tactical Radio System (JTRS) ❑ C (RISC) ❑ Improved data latency protocol and techniques like 3G wireless ❑ UAV and HAA demonstrations and developments ❑ Faster routers and switches ❑ D3 NASA Project ❑ DARPA's Next-Generation (XG) Communications Program ❑ DARPA BLAST Program to address multipath interference ❑ Deep Space Network Frequency and Timing by NASA JPL ❑ Modulation techniques: FSK, FM/FM, QPSK, PM, BPSK, Feher-patented Quadrature Phase Shift Keying (FQPSK-B), Continuous Phase Frequency Shift Keying (CPFSK) ❑ Protocols: Voice Activity Detection (VAD), Resource Reservation Setup Protocol (e.g., RSVP), Real-time Transport/Control Protocol (RTP/RTCP)

Power Systems for Transceivers Aboard Flight Vehicles and Satellites

Space-based and mobile range assets that would perform communication relay functions on future ranges would be improved by more advanced power systems for transceivers. In addition to the technology development for low-power transceivers proposed in the Telemetry section, transceivers for telemetry (including tracking data from on-board GPS-based and inertial systems) and command and control aboard flight vehicles to be tested or operated on ranges would also be enhanced by more advanced power systems. As noted in the table above, a variety of technology options exist for such on-board power systems.

Proposed Development Steps for Power Systems for Transceivers Aboard Flight Vehicles and Satellites

- **Advocate NASA Fuel Cell Research**, including projects at Glenn Research Center (GRC) and Langley Research Center (LaRC).
- **Advocate Solar Power Technology Development,** including projects at NASA's Jet Propulsion Lab.
- **Pursue Battery Technology Development,** including demonstrations of polymer ion batteries like those developed for the VBITS low-power transceiver.
- **Advocate Other Power Generation Technology Development,** including flywheel research, nanoconverter, and nuclear power research.

Antenna Technology

Another way to improve the capability of space-based and mobile platforms to relay telemetry, command and control, and communications is to pursue improved antenna capabilities by developing new materials and technologies. For instance, there are commercial services available that provide two-way broadband data services to mobile users aboard aircraft at 5 Mbps receive and 1.5 Mbps transmit data rates. More testing and development must to be accomplished to determine the full potential associated with broadband satellite capabilities as range data relay assets required to maintain reliable links with fast-moving and accelerating aircraft, missiles, and launch vehicles.

Proposed Development Steps for Antenna Technology

- **Pursue Phased-Array Antenna Research and Development**, including demonstrations involving broadband data relay using through satellites from phased-array antennas aboard aircraft, missiles, or rockets, reconfigurable phased array satellite antennas, and other phased array antenna research like that being pursued by NASA, the Air Force and the Navy.
- **Advocate Tunable Antenna Technology Development,** including the various frequency-agile electronic materials, circuits, and antenna aperture projects being pursued by NASA and DARPA. Other related examples include software-reconfigurable radios and capabilities for satellites and ground user equipment.

Advanced Communication Network Technology

The Global Range Communication System will not only rely on mobile- and space-based assets, an advance terrestrial network will be the backbone. This communication network will provide high bandwidth voice, video, data, and timing services seamlessly through integrated space, mobile, and ground systems.

Proposed Development Steps for Advanced Communication Network Technology

- **Pursue Advance Protocol Development That Seamlessly Integrates Space, Mobile, and Ground Communication Systems,** including for example, Next Generation Internet (NGI), the DoD Transformational Communication System (TCS) (currently in the early stages of development), IP in Space, Interplanetary Internet.
- **Advocate Continued Research Into High Bandwidth Network Technology**, including flexible and dynamic high bandwidth allocation, Quality of Service (QoS), Advance networks and software algorithms and lossless, low-latency data compression techniques.

Alternative Uses of Frequency Spectrum, Including Lasers, Free Space Optical Communications

To address the need for high data rate telemetry and communications relay in the face of uncertain future frequency spectrum assignments, free space optical and other laser communications at unregulated optical wavelengths offer some potential advantages. Other innovative approaches could include research into ways to use reflections and scattering of signals or continuously monitoring spectrum use and coordinating jumps to other frequencies that are not being used to capacity continuously in time or at specific locations.

Proposed Development Steps for Alternative Uses of Frequency Spectrum

- **Pursue Demonstrations Using Laser Communication Systems on Space-Based and Mobile Platforms,** including for example, the DoD Transformational Communication System (TCS) (currently in the early stages of development), ARTEMIS - a European Space Agency (ESA) satellite with a 10-year operating life remaining, and NASA's projects to develop optical communications to and from spacecraft, ground stations, and mobile platforms.
- **Advocate Continued Research Into Innovative Alternative Uses of Frequency Spectrum**, including for example, Ultra-Wideband (UWB), Bell Labs' Blast program using array antennas to divide and transmit data in multiple streams on the same frequency, so the signals are distributed in space as well as time[4], and DARPA's Next Generation (XG) program[5] to rapidly monitor and change frequencies to take advantage of portions of the frequency spectrum that are not being continuously used to capacity.

Additional Areas for Focused Development

More Efficient Transceivers	Antenna Technology	Advanced Network Technology	Alternative Uses of Frequency Spectrum	Multiuse UAVs	Information Assurance Approaches
• Light weight, high energy-density batteries	• Multi-mode antennas	• Protocols to integrate voice, video, data	• Using variations in plasma field for comm	• Area surveillance	• Spot beams
• Micro fuel cells	• Steerable on-orbit antennas	• Wireless and Mobile Protocols	• Spread spectrum	• Telemetry collection	• Encryption
• High-temperature semi-conductors for power amps	• Cooling for phased arrays	• Scintillation coding techniques	• Autonomous, self-reacting spectrum characterization and coordination	• Communication relay	• Autonomous detection
	• Phased arrays capable of operating at higher frequency	• Multiplexing	• Signal priority processing	• Optical tracking	• Frequency hopping
	• Electronic steering technology for phased arrays	• Faster, more efficient compression algorithms	• Millimeter wave radio-frequency circuits and devices	• Testing of space-based capabilities like laser links	• Mobile ad hoc IP
	• Carbon composite phased array structures	• Low loss, high ratio, low latency compression (e.g., wavelets)	• 60 GHz oxygen absorption links		
	• Microelectro-mechanical systems (MEMS) nano-technology	• Encryption techniques	• Laser tracking and pointing		
		• Throttleable Bandwidth	• Free space optics		
			• Frequency hopping		

Record and Archive Data

The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the ability to record and archive data.

Far-Term Objectives for Recording and Archiving Data			
Far-Term Objectives (FY 2016-2028)	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Compatibility ❑ Data Access ❑ Media Transition ❑ Post-Op Support/ Analysis	❑ Physical aspects of storing data - making it scalable ❑ Large amounts of data ❑ Multiple data formats including many analog systems ❑ Data access retrieval ❑ Data medium conversion ❑ Data protection ❑ Tools used to store and archive data	❑ High density storage media ❑ Lossless data compression ❑ Web-based browser access to data via Internet ❑ Data format standardization (digital formats) ❑ Data mining and databases	❑ Silicon Micro-Disk ❑ Patterned Magnetic Media ❑ COTS digital read/write products ❑ Blue laser optical disk ❑ Commercial data conversion and compression techniques ❑ FROST by Call/Recall Inc. and DARPA ❑ Automated media library ❑ Hybrid storage by DARPA/IPTO

The ability of future ranges to record, store, and archive large amounts of data would be enhanced by higher-density storage media that is less sensitive to environmental conditions over time, improved data compression techniques, processing at the data source, centralized storage, standard protocols for media and data formats, improved search engines, and network-based access capabilities.

Proposed Development Steps for Recording and Archiving Data

- **Leverage Commercial Development of High-Density Data Storage Technology,** including both optical and magnetic media.
- **Leverage Signal Processing Efforts**, particularly those focused on data compression and error correction.
- **Advocate Multi-Protocol Label Switching (MPLS),** as a means of driving toward standardization.
- **Leverage Commercial Network Development for Data Storage and Retrieval**, including search engines and next-generation Internet.

Additional Areas for Focused Development

Other Technologies for Recording and Archiving Data
• Information mining techniques
• Bit-oriented volumetric storage media with high-capacity, high-throughput, removable optical memory disk system
• Molecular photography data storage technology
• Organic, cellular, or tissue-based memory subsystems
• 3-D data storage technology
• Data compression
• Intelligent query systems
• Data storage and retrieval systems and media that require no environmental controls

Administer and Manage Communication Network

The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the ability to administer and manage the communication network.

Far-Term Objectives for Administering and Managing the Network	
Far-Term Objectives (FY 2016-2028)	**Technical Challenges and Approaches**
❑ Administration and Management ❑ Distribute Real-Time Data ❑ Security	❑ End-to-End Quality of Service (QoS) ❑ Flexible and Dynamic Bandwidth Allocation ❑ Security - authentication, intrusion detection, user access, encryption ❑ Secure open network ❑ Protocol standardization ❑ Remote monitoring and repair ❑ Self-organizing networks ❑ Auto-reconfiguration ❑ Availability (continuous, on demand, global) ❑ Reliability

The ability of future ranges to administer and manage the communication architecture is enhanced by various network technologies and approaches, including use of mobile or space-based assets for signal relay, signal processing (i.e., data compression, error correction, modulation techniques, etc.), antenna technologies, and alternative uses of frequency spectrum (e.g., free space optics, laser communications) as highlighted in the Tracking and Surveillance, Telemetry, and Command and Control sections. Other examples of technology development to enhance the ability to administer and manage the communication network include:

Proposed Development Steps for Administering and Managing the Network

- **Leverage Commercial Development of Network Technologies and Infrastructure,** including data packaging methods, router, server, and storage capabilities, and administration approaches.
- **Advocate Technology Development To Automate Network Management,** including rule-based database and lookup technologies as well as categorization algorithms.

Additional Areas for Focused Development

Other Technologies for Administering and Managing the Network
• Common protocols for satellite, mobile, and ground systems
• Mobile Ad Hoc Network Technology (MANET)
• Wavelength Division Multiplexing component and network technologies
• Distributed, real-time, and embedded (DRE) “systems of systems”
• Single, global, scalable, resilient MPLS-enabled backbone
• Wideband network waveforms (WNWs)
• Improved routing algorithms and dynamic switching
• Network traffic monitoring
• Autonomous, self-learning technologies
• Self-repairing/ maintaining equipment

Communication Architecture Technology Roadmap (see Figure 19)

Key technologies for communication architecture include space-based and mobile platforms; improving distribution of voice, video, and data through improved ground networks like the Next-Generation Internet or the Global Information Grid; improved signal processing for data compression and error correction; enabling use of unregulated, unassigned, or unused frequency spectrum; antenna technologies; longer-lived, more efficient optical and magnetic storage media; and advanced data handling.

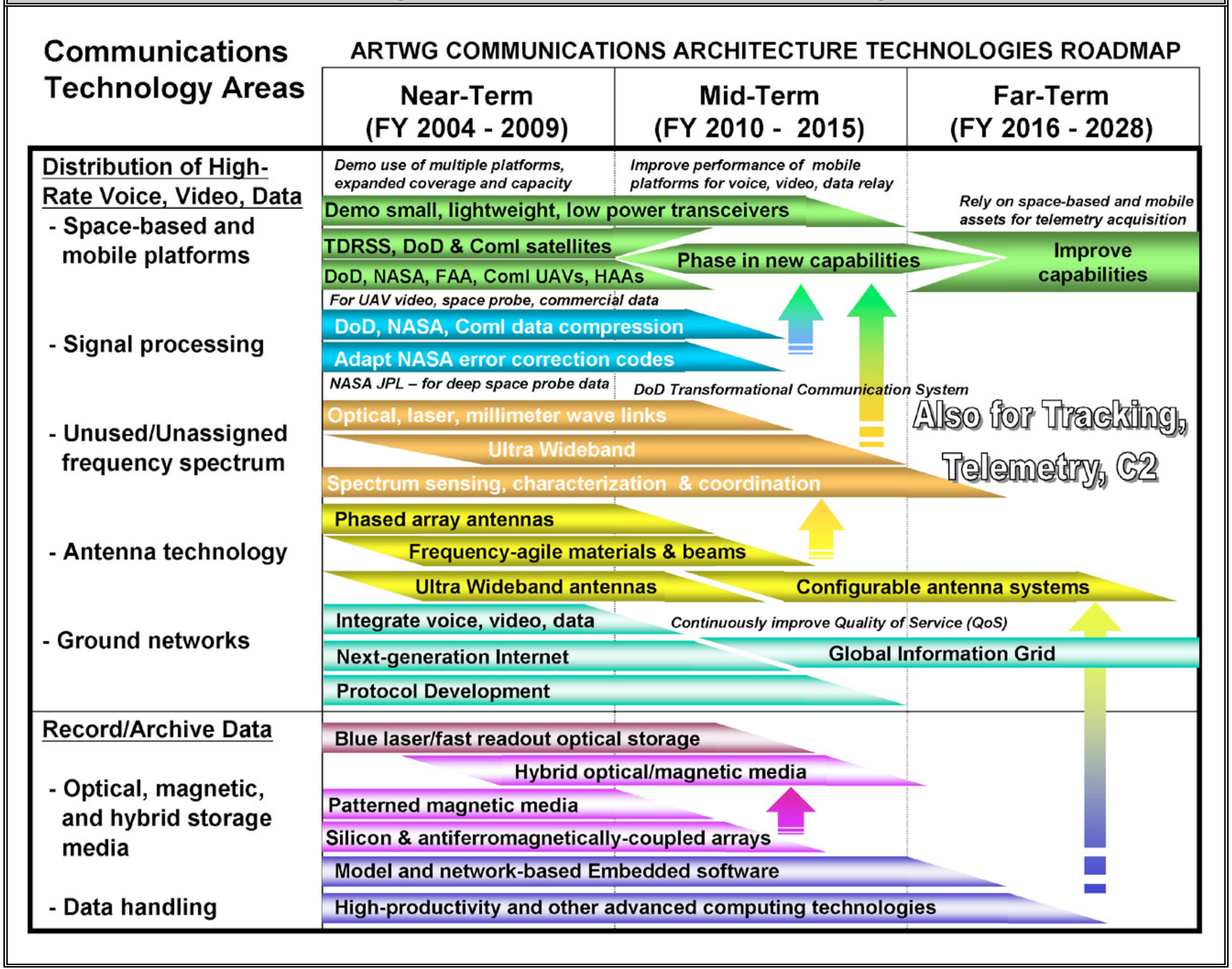


Figure 19 Technology Roadmap for Communication Architecture

RANGE COMMAND AND CONTROL SYSTEMS (RCCS)

RANGE COMMAND AND CONTROL SYSTEMS

The following top-level capability roadmap (see Figure 20) lists the qualitative goals for improved range command and control capabilities over time, as previously summarized with the other range functions.

ARTWG envisions Command and Control capabilities evolving over time toward autonomous knowledge-based functions based on sophisticated fusion algorithms and data distributed on a robust, virtual, self-organizing network, providing increasingly interoperable, responsive, and flexible range and flight safety support for global operations.

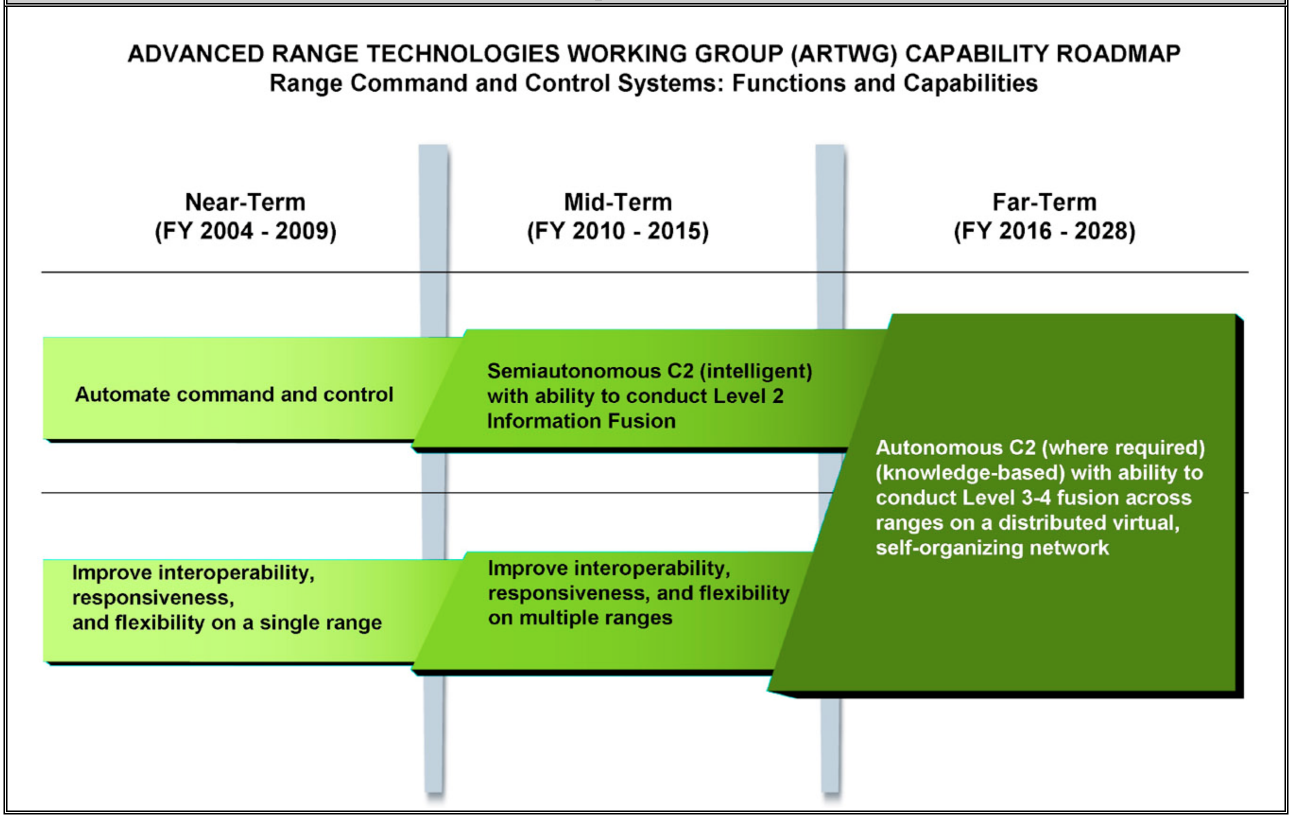


Figure 20 Capability Goals Over Time: Command and Control

Data or information fusion definitions include the following:

a. Level 0, Sub-Object Assessment: Pixel/signal level data association and characterization.
b. Level 1, Object Assessment: Observation-to-track association, continuous state estimation (e.g., kinematics) and discrete state estimation and prediction.
c. Level 2, Situation Assessment: Object clustering and relational analysis, to include force structure and cross force relations, communications, physical context, etc.
d. Level 3, Impact Assessment: Plans refinement, plans intent estimation, event prediction, consequence prediction, susceptibility and vulnerability assessment.
e. Level 4, Process Refinement: Adaptive search and processing (an element of resource management) to improve situations and plans.

The following subfunctions and capability goals (see Figure 21) were identified by the subgroup as elements of the range command and control function:

Subfunctions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Far-Term (FY 2016 - 2028)
Monitor Range Asset Health, Status, and Configuration	❑ Semiautomated systems using shallow information extraction (rule-based) ❑ Common operating picture of 1 individual range with enhanced human interface utilizing 3-D animated graphics on 1 screen ❑ Provide real-time command and control capability ❑ Connectivity with remote status and health displays ❑ Automatic exclusion of nonmission capable assets from available inventory	❑ Automated systems using Intermediate information extraction (fuzzy logic) ❑ Access to common integrated operating picture of multiple ranges with enhanced human interface utilizing 3-D animated graphics of 1 screen. ❑ Automatic recognition of all systems within an region and display to operator ❑ Automatic call-up of options or automatic reconfiguration options for human selection	❑ Autonomous exploitation of data using deep information extraction (expert systems)--Data sources interact to produce additional data ❑ Access to common integrated operating picture of network of ranges with enhanced human interface utilizing 3-D immersion environment for display (e.g., holographic deck, CAVE, etc.) ❑ Automatic recognition of all systems within national system ❑ Self-healing systems
Configure Range Assets	❑ Local remote and automatic configuration ❑ Centralized automated and manual configuration of range assets ❑ Generate configuration files electronically from operations directives	❑ Regional control and configuration ❑ Semiautomated	❑ Global control and configuration ❑ Balance automatic /self-configuration with omni-present systems
Execute Command and Control of Range Assets and Flight Vehicles 1. Generate command(s) 2. Publish the command(s) 3. Transmit the command(s) 4, Receive/implement the command(s) 5. Verify effectiveness of command(s)	❑ Enhanced Flight Termination System (FTS) ❑ Autonomous demonstration ❑ Satellite transmission demonstration ❑ Systems engineering to enable centralized control with some automation across single range ❑ Semiautomatic global flight safety system	❑ Next Generation FTS ❑ Some use of autonomous systems for FTS and range assets ❑ Implementation of satellite transmission ❑ Systems engineering enabling centralized control and automation across multiple ranges ❑ Use of soft configurable systems such as flexible wave forms ❑ Full automatic global flight safety system	❑ Fully “virtual” FTS ❑ Full FTS autonomy (while maintaining capability for manual FTS if required) ❑ Full centralized control and automation across multiple ranges (Global Range Control) with decentralized execution ❑ Extensive use of soft configurable systems such as flexible wave forms ❑ Full autonomous global flight safety system

Figure 21 Command and Control Subfunctions and Capability Goals Over Time

The following tables further address each subfunction (Monitor, Configure, Execute) by listing a number of quantifiable performance objectives, associated technical challenges, and technical approaches that could be pursued to achieve the performance objectives. The tables also list a number of current projects underway that could enable the development or demonstration of technologies and systems that address the technical challenges. Following each table is a description of the projects underway, and the technology needs that remain to enable achieving the objectives.

Monitoring Range Assets

The first subfunction in dealing with command and control on space launch and test ranges is monitoring the health, status, and configuration of the range assets. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address monitoring the health and status of range assets.

The DoD and NASA range communities should consider supporting various ongoing Government and commercial efforts focused on developing standard interfaces to enable development and use of “plug and play” data fusion algorithms. In the near-term, this allows range technology to progress through Level 0, Sub-Object Data Association and Estimation to Level 1, Object Refinement, permitting observation-to-track association, continuous state estimate, and discrete state estimation (target type and identification) and prediction. Additionally, DoD and NASA should pursue the rule-based data extraction technology such as that being developed for the Multisensor Command and Control Aircraft (MC2A). This next-generation command and control aircraft will serve as an intelligence, surveillance, and reconnaissance platform, fully interoperable with other aircraft and unmanned systems, and capable of integrating those signals with signals gathered from the aircraft’s own tracking systems. A third technology that DoD and NASA should consider supporting to meet the technical challenge of transforming data displays into information dissemination is the imagery registration used in the processing of commercial remote sensing data by overlaying two or more images or data sets to enable the synergistic use of multiple types of information. Specific near-term steps could also improve the ability of ranges to monitor asset health, status, and configuration.

Far-Term Objectives for Monitoring Range Assets

Far-Term Objectives (FY 2016-2028)	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ Autonomous exploitation of data using deep information extraction (expert systems)--Data sources interact to produce additional data ❑ Access to common integrated operating picture of network of ranges with enhanced human interface utilizing 3-D immersion environment for display (e.g., holographic deck, CAVE, etc.) ❑ Automatic recognition of all systems within national system ❑ Self-healing systems	❑ Knowledge of asset status ❑ Self-configuring systems ❑ Integration of scheduling systems and assets ❑ Interoperability and compatibility among sensors, data, displays ❑ Distributed locations of sensors - maintenance challenges ❑ Acquire and process larger volumes and more frequent sampling rates for sensor data ❑ Ability to process data with high data loss or errors ❑ Transform data displays into information dissemination ❑ Development of “intelligent” sensors	❑ Self-diagnosis ❑ Self-healing systems ❑ Automatic switching to usable assets ❑ Modeling tools that predict failure modes and areas, determine redundancies needed ❑ Common protocols ❑ Intelligent systems ❑ Autonomous systems ❑ Auto debugging devices ❑ Integrated health monitoring and management systems for flight vehicles and range systems ❑ Standard interfaces to enable development and use of plug and play data fusion algorithms ❑ Automated problem analysis of historical sensor data ❑ Infrastructure network (e.g., internet) ❑ Protocols ❑ Front-end interfaces ❑ Information pedigree, time-tagging ❑ Intelligent, configurable sensors with on-board processing ❑ DoD ASD(C3I) thrust toward all-IP-based data transfer infrastructure for terrestrial GIG and wireless systems like JTRS ❑ DoD move toward Task- Post-Process-Use versus traditional Task-Process-Exploit-Disseminate ❑ Policy-based dynamic bandwidth and resource allocation for SATCOM systems ❑ Bandwidth-efficient modulation techniques ❑ Statistical multiplexing gains from on-board packet-switching capability aboard IP-based communication satellite platforms ❑ Software wrappers so legacy systems can plug and play ❑ Data fusion and information extraction/mining techniques ❑ Scalable, load-balanced telemetry processors ❑ Automated data error correction routines ❑ Compilation and organization of data into graphical, hierarchical information displays	❑ “RAPTOR” (HFOTEC) ❑ Artificial intelligence tools ❑ SLRSC at Western Range/Eastern Range (WR/ER) ❑ Automotive diagnostic systems (e.g., systems in use on automotives) ❑ Test solutions LLC built-in test equipment ❑ Frontier Technologies ❑ Automatic deconfliction engines for scheduling (e.g., Quantum Leap Innovations) ❑ Basic knowledge-based system ❑ Workflow systems ❑ IP in space ChIPSat (NASA) ❑ DoD’s Transformational Communication System (TCS)-laser links ❑ NASA’s Interplanetary Internet ❑ NASA JPL Deep Space experiment and optical communications initiative ❑ Waveguide Laser for High Data Rate Deep Space Communications by NASA JPL ❑ Data Intensive Systems (DIS) by DARPA/IPTO ❑ NASA JSC MCC architecture initiative ❑ NASA MSFC Ground Systems Dept distributed operations system for ISS ❑ Missile Defense Agency BMC3 ❑ Mobile ad hoc network technology (MANET) by Internet engineering task force ❑ JPL turbo codes ❑ JSC-Ames Information Sharing Protocol ❑ LIDAR Applications Group, Atmospheric Sciences Division at the NASA LaRC since 1978 ❑ EO, RF, sensor technologies in development by AFRL Sensors Directorate (at WPAFB, OH) ❑ DoD Transformational Comm System (TCS) lasercom from UAVs to satellites ❑ Information Fusion Technologies (AFRL/IF) ❑ Software wrappers Incremental Upgrade of Legacy Systems (IULS) AFRL/IFTA ❑ FAA/DOT traffic management, telephone routing, robotic 3-D vision, NOAA use of satellite sensor data ❑ NASA JSC MCC Mission Data Storage Consolidation project ❑ NASA MCC FEP replacement project ❑ NASA JSC MCC technology demo project ❑ MCC-5-year vision ❑ Range control software

Proposed Development Steps for Monitoring Range Assets
• **Adapt Software Wrapping Programs such as the Incremental Upgrade of Legacy Systems (IULS), sponsored by AFRL/IFTA**. This technology, developed and demonstrated by Boeing, consists of a software program that "wraps" around both the legacy avionics software and new software, allowing both to operate in an upgraded system. The approach allows operational flight programs to leverage proven software while incrementally introducing lower cost, commercial software and hardware, reducing the time and cost of upgrading systems.
• **Leverage Built-in Test and System Health Monitoring Technologies Used in Automotive and Other Diagnostic Systems To Predict and Isolate Failures**. Blackbox Solutions LTD developed a small, light, and portable system (ROVACOM) to quickly diagnose the health of Range Rover vehicles. Test Solutions LLC designs and manufactures products that utilize built-in measuring, monitoring, and testing technologies for major manufacturers such as Ford, Johnson Controls, and Panasonic.
• **Pursue Synergy With DARPA, AFRL, and Other Agencies' Projects To Develop Newer/Smarter Sensors, Using Micro Electromechanical Systems (MEMS) Technologies, Nano-Technologies and Biotechnologies.**

Additional Areas for Focused Development

Other Technologies for Monitoring Range Assets
• Information pedigree, time-tagging
• Tools for creating and presenting a common operating picture for individual and multiple ranges
• Upper level information fusion (levels 2-3) (AFRL/IF)
• Lasercom pointing techniques
• Information extraction/mining techniques (AFRL/IF)
• Information and Intelligence Exploitation (AFRL/IF)
• Multisensor Exploitation (AFRL/IF)
• Advanced visualization and 3-D holographics displays

Configuring Range Assets

The next subfunction dealing with command and control on space launch and test ranges is to configure range assets. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address configuring range assets.

Far-Term Objectives for Configuring Range Assets

Far-Term Objectives (FY 2016-2028)	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ Global control and configuration ❑ Balance automatic/ self-configuration with omnipresent systems	❑ Self-configuring systems ❑ Integration of scheduling systems and assets ❑ Leveraging from a simple signal - multiple users using a common frequency at the same time ❑ Multiple users using the same range systems at the same time.	❑ Intelligent systems ❑ Integrated health monitoring and management systems for flight vehicles and range systems ❑ Standard interfaces to enable development and use of plug and play ❑ Fusion algorithms (to plug and play) ❑ Automated problem analysis of historical sensor data ❑ Infrastructure architecture (e.g., internet) ❑ Protocols refinement and development ❑ Front-end interfaces ❑ Standard interfaces to enable development and use of plug and play ❑ Data fusion algorithms ❑ Adaptive, expert system to assemble data into real-time situational awareness information ❑ Intelligence Information and fuzzy logic to support real time development of courses of action while operations are ongoing ❑ Use of COTS hardware and software, where practical, to perform command and control functions (e.g., PDAs) from remote locations to generate and transmit commands over secure networks ❑ Develop new multiplexing techniques (software defined) ❑ Continuously available systems (i.e., always on)	❑ Artificial intelligence tools ❑ SLRSC at WR/ER ❑ Automotive diagnostic systems (e.g., Rovacom for Range Rover) ❑ Test solutions LLC built-in test equipment for Ford, Johnson Controls, Panasonic ❑ IP in space—ChIPSat (NASA) ❑ DoD's Transformational Communication System (TCS)-laser links ❑ NASA's Interplanetary Internet ❑ NASA JPL Deep Space experiment and optical communications initiative ❑ Waveguide Laser for High Data Rate Deep Space Communications by NASA JPL ❑ Data Intensive Systems (DIS) by DARPA/IPTO ❑ NASA JSC MCC architecture initiative ❑ NASA MSFC Ground Systems Dept distributed operations system for ISS ❑ Missile Defense Agency BMC3 ❑ Mobile ad hoc network (MANET) by Internet engineering task force ❑ JPL turbo codes ❑ JSC-Ames Information Sharing Protocol ❑ GPS, TDRSS ❑ Global Information Grid (AFRL/IF)

The Missile Defense Agency is pursuing technology and capability demonstrations that are useful in making global command and control a reality.

Proposed Development Steps for Configuring Range Assets

- **Leverage Capabilities Being Demonstrated in the Missile Defense Agency Battle Management Command, Control, and Communications (BMC3) System for range equipment.** The BMC3 coordinates command and control data from multiple sensors and an interceptor, allowing interoperability across multiple ranges and time zones.
- **Leverage New Technology Recently Deployed for Wallops Flight Facility Range Control Center.** The WFF RCC is adopting a new concept of operations and COTS-based range C2 infrastructure for handling multiuser and multisource range operations.
- **Create Range Operations Testbed.** A facility for experimenting and testing new command and control technologies in a laboratory environment (isolated from range ops but able to interact when needed) is needed.

Additional Areas for Focused Development

Other Technologies for Configuring Range Assets
• Integrated health monitoring and management systems for flight vehicles and range systems
• Standard interfaces to enable development and use of plug and play data fusion algorithms
• Information fusion (levels 2-4) (AFRL/IF) techniques for fusing real-time data and model simulations (for continuously and automatically assessing the fall out and drift of a flight termination using dispersion models in real-time)
• Advanced model abstraction (AFRL/IF)
• Multiresolution modeling for courses of action (COA) development (AFRL/IF)
• Situational assessment within global environment (AFRL/IF)

Executing Range Command and Control

The final subfunction in ensuring effective command and control on future space launch and test ranges is executing commands to control range assets. It is worthwhile to note that range safety is primarily policy driven; however, advances in technology can provide a change in (or addition of) policy (i.e., push-pull characteristics). The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address executing range command and control for both range assets and flight vehicles.

Far-Term Objectives for Executing Range Command and Control			
Far-Term Objectives (FY 2016-2028)	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Fully "virtual" FTS (where appropriate) ❑ Full FTS autonomy (while maintaining capability for manual FTS if required) ❑ Range Systems ❑ Full centralized control and automation across multiple ranges (Global Range Control) with decentralized execution ❑ Extensive use of soft configurable systems such as flexible waveforms (adaptable transmissions)	❑ Automating the command generation process ❑ Timely distribution of commands to all locations necessary to implement the selected COA, and timely return of verification data ❑ Generation and transmission of commands from remote locations ❑ Interpret command responses and generate recommended courses of action for rejected commands ❑ Integration of command and telemetry into a generalized communications link	❑ Evolve command generation from rule-based, to fuzzy logic, to intelligent systems ❑ Network technologies to link multiple-ranges and assets at dispersed remote locations ❑ Use of personal digital assistants (PDAs) from remote locations to generate and transmit commands over secure networks ❑ Intelligent command response logic with decision tree analysis ❑ Self-organizing and self-healing network technologies ❑ Compression software ❑ Satellite relay ❑ Flight hardware	❑ NASA MSFC Ground Systems Dept distributed operations system for ISS ❑ NASA JSC MCC architecture initiative ❑ MCC-15 year vision ❑ DoD Transformational Comm System (TCS) for satellite laserlinks and software-reconfigurable network ❑ Commercial Internet backbone service providers (e.g., UUNET) ❑ Missile Defense Agency BMC3 ❑ Mobile ad hoc network technology (MANET) by Internet engineering task force ❑ UAV development by DoD and NASA ❑ High-Altitude Airships (HAA) by ACTDs by MDA, NORAD, Army, Navy, and FAA ❑ VISA ❑ STARS

The ability to execute command and control of range assets and flight vehicles on future ranges would be enhanced by the same technology development and demonstration activities as previously noted for Telemetry and Communications Architecture involving UAVs, HAAs, low-power transceivers, alternative approaches to the use of frequency spectrum, and antennas. In addition, for future ranges using space-based range assets to maintain a robust, two-way data link with flight vehicles for both telemetry and commanding, it would also be worthwhile to demonstrate the use of satellites as the primary telemetry and commanding capability for down-range operations requiring hemisphere- or global-scale range coverage, where the time delay can be accommodated without adversely impacting the safety of range-supported operations.

Proposed Development Steps for Executing Range Command and Control
• **Explore the Concept of Using a Space-Based Platform To Send Range Safety Commands.** Given the desirability of moving toward a space-centric range architecture for the future, it would be both feasible and worthwhile to conduct an experiment using TDRSS to measure the data latency associated with a telemetry and command path between a flight vehicle and a range through a GEO satellite. Such a demonstration has been proposed by NASA Goddard Space Flight Center.[6] Since 1994, TDRSS has been providing telemetry links from upper stages back to the ground during ELV launches. Since 1996, NASA Goddard has been exploring the concept of using TDRSS to provide a forward command link capability as well.
• **Advocate Implementation of the CPFSK Digital Command Protocol Identified by the Enhanced Flight Termination System (EFTS) Study**.[7] The EFTS study was conducted between late 2000 and 2002 by NASA KSC and Dryden Flight Research Center (DFRC) with Air Force participation and Range Commanders Council oversight to address the vulnerabilities of analog range command signals that have been in use since the 1950s. It recommended a Continuous Phase Frequency Shift Keying (CPFSK) digital modulation scheme to improve reliability, latency, and immunity to interference. It recommended changes to RCC standards and three technology demonstrations through 2006 with flight hardware on active U.S. ranges.

Additional Areas for Focused Development

Other Technologies for Executing Range Command and Control
• Fuzzy logic and intelligent information systems
• Self-organizing and self-healing network technologies
• Self-aware network
• Vertically interconnected technologies used simultaneously
• Low-power and compact spectrum-sensing technologies
• Autonomous, self-reacting spectrum characterization and coordination

Command and Control Technology Roadmap

The following technology roadmap (see Figure 22) displays the major technology areas, with time-phased recommendations regarding particular technologies to pursue in improving the ability of space launch and test ranges to conduct command and control activities.

Key technologies for command and control include monitoring range assets, automating reconfiguration capabilities, and executing commands through a robust two-way data link shared with the vehicle telemetry link.

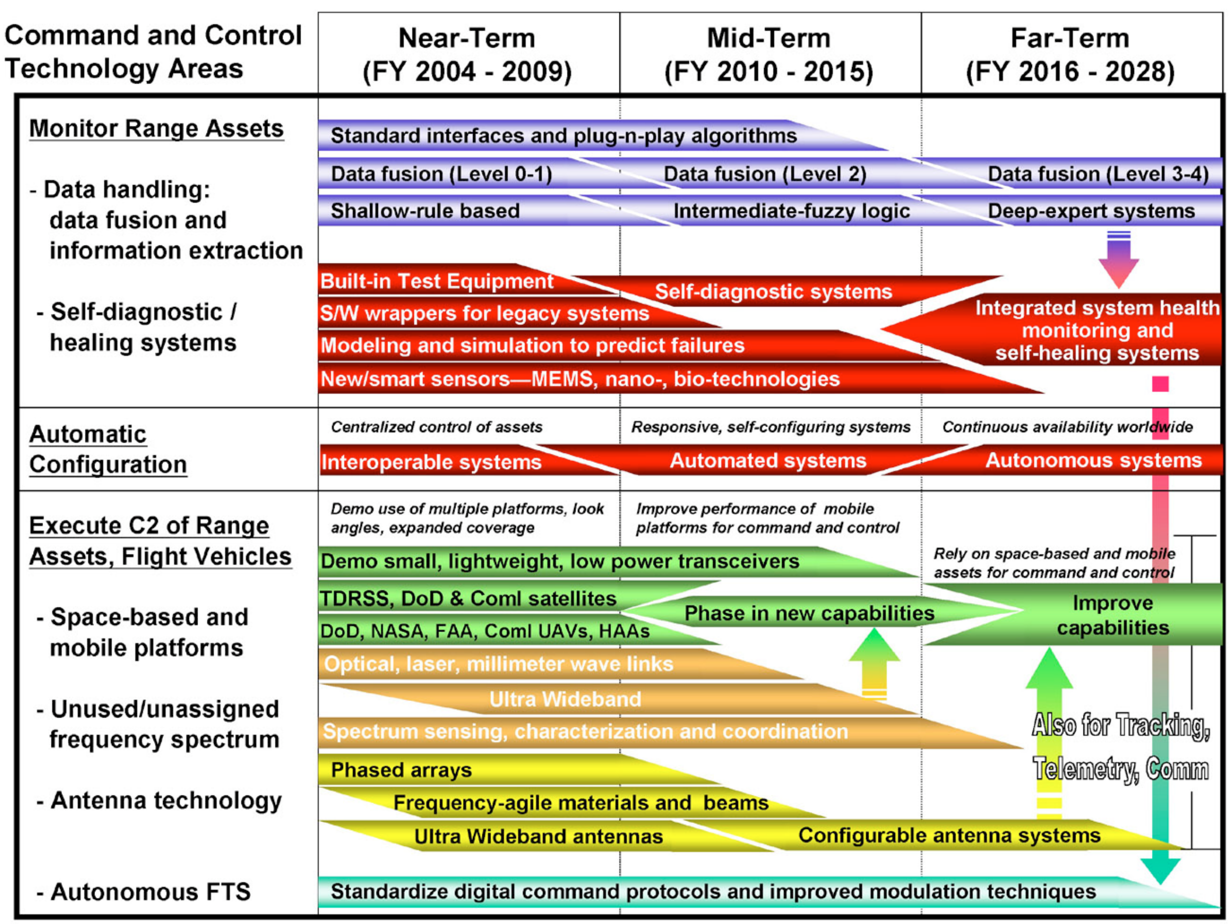


Figure 22 Technology Roadmap for Command and Control

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DECISION MAKING SUPPORT

DECISION MAKING SUPPORT

The following top-level capability roadmap (see Figure 23) lists the qualitative goals for improved range decision making support capabilities over time, as previously summarized with the other range functions.

ARTWG envisions Decision Making Support capabilities evolving over time toward increased standardization in modeling and simulation, collision avoidance, and sophistication of 2-D and 3-D immersion-type displays.

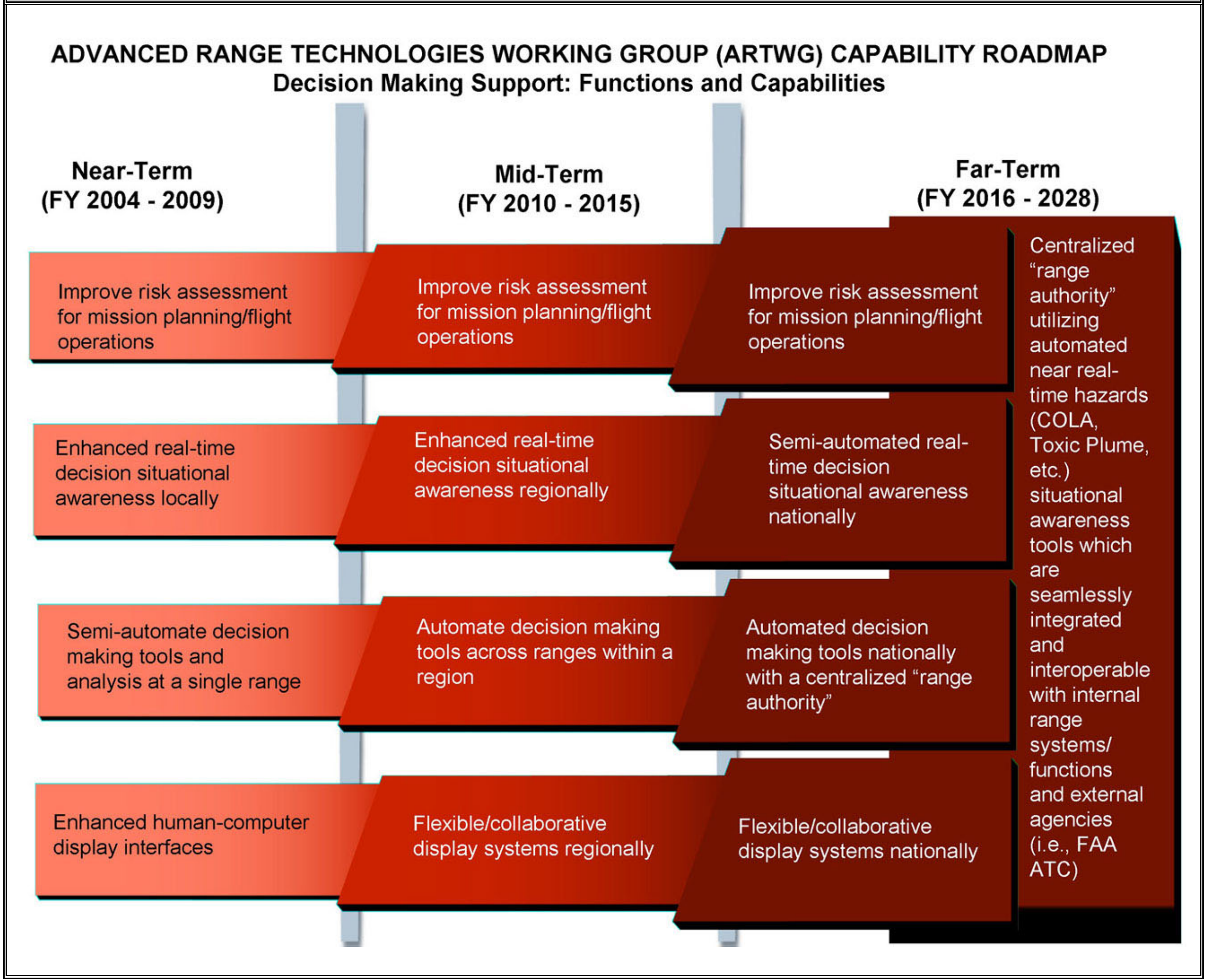

Figure 23 Capability Goals Over Time: Decision Making Support

The following subfunctions and capability goals (see Figure 24) were identified by the subgroup as elements of the decision making support function:

Sub-functions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Far-Term (FY 2016 - 2028)
Perform risk analysis (preflight, flight, and landing)	❑ Semiautomated risk management and analysis at a single range ❑ Commit criteria responsive (e.g., improved vehicle reliability and characterization, ongoing toxicological updates) ❑ Interactive simulation of nominal and nonnominal trajectories ❑ Longer forecasts and better use of climatology ❑ Semiautomate models (real-time tracking, monitoring) ❑ Increased accuracy and fidelity of models and processes ❑ Improved temporal/spatial models (i.e., toxic cloud) ❑ Faster, higher fidelity interactive models (blast, toxics, debris, and vehicle breakup characteristics and reliability) ❑ Improved standard environment definitions and databases (population densities, terrain, buildings, toxicology, atmospheric properties, and failure modes) ❑ Flight plan timelines decrease to 1 month ❑ Responsive approval process for both established and unproven vehicles ❑ Model execution in minutes ❑ Maintenance trends monitored and factored into risk calculations ❑ Reduce uncertainty of customer-supplied data (standardized criteria as affected by vehicle and varying flight paths)	❑ Integrated, semiautomated risk management and analysis nationally ❑ Adaptable to various levels of risk (affects level of coordination required) ❑ Automated high-fidelity models with greater accuracy and increase confidence in results ❑ Flight plan timelines decrease to 1 day ❑ Dynamic interactive models ❑ Improved breakup characterization ❑ Increased vehicle reliability	❑ Integrated automated risk management and analysis globally ❑ Improve flexibility for managing diverse risk while minimizing impact to cost and schedule ❑ Integrated, automated models and processes of high fidelity and accuracy incorporating real-time tracking, sensing, and monitoring data ❑ Quantifiable (with high confidence) risk in a given environment ❑ Flight plan timelines decrease to 2 hours ❑ Continuous model execution ❑ Intelligent launch vehicles with increased reliability and maintainability

Sub-functions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Far-Term (FY 2016 - 2028)
Maintain "real-time" flight safety ops (while traversing airspace)	❑ Improved integration of systems between ranges and FAA ❑ Integration of spaceport status for dynamic routing and abort/landing scenarios.	❑ Additional, short-duration restricted flight zones ❑ Migrate towards traffic management system) ❑ Flexibility to choose which spaceport to launch/land from	❑ Data quickly available to all stakeholders (such as back to FAA to identify air lane restrictions – shorter restricted times may make airlines more receptive ❑ Seamless and fully integrated air and space traffic monitoring and control (Policy, Spaceport also) ❑ Schedule options not dependent on other users
Maintain situational awareness (real-time ops)	❑ Automated analysis and prediction with collision effects modeling and simulation ❑ Enhanced collision avoidance situational awareness locally ❑ Improved ground surveillance ❑ Integrate data from multiple spaceports	❑ Automated and integrated with other ranges/spaceports/agencies nationally ❑ Integrated collision avoidance situational awareness nationally	❑ Continuous updates of Safety COLAs ❑ Continuous updates of mission assurance COLAs to produce integrated launch opportunities and windows ❑ Dynamic global situational awareness ❑ Multi-spacecraft simulations that predict time and location of potential congestions
Fuse and Process information provided by the other range functions and external agencies	❑ Improved integration with other range functions, spaceports, and agencies ❑ Semiautomated data inputs to models ❑ Standardize communications and data exchange protocols ❑ Improved interrange planning and coordination procedures (Planning and Scheduling) ❑ Increase communication and data processing bandwidth (Comm) ❑ Support 4 simultaneous operations ❑ Common use of intelligent automated rule-based systems across a single range ❑ 3-second assessment	❑ Open architectures ❑ Interoperability with other range functions and agencies ❑ Automated data inputs to models ❑ Decision Support Tools (DSTs) directly linked with other systems-admin, etc. ❑ Support 4-21 simultaneous operations ❑ Increased use of semi-autonomous (intelligent) systems (with ability to conduct level 2 fusion) across multiple ranges ❑ Near continuous assessment	❑ Seamless and integrated data flow and decision support tool with all stakeholders ❑ Ease of expandability and upgrade at minimal cost ❑ Dynamic/flexible airspace ❑ Less constraint oriented ❑ Support 21 simultaneous operations ❑ Fully autonomous systems that are knowledge-based (environmental and situational awareness) with ability to conduct level 3-4 fusion across a network of ranges ❑ Near continuous analysis and COA assessment

Sub-functions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Far-Term (FY 2016 - 2028)
Present/ display information for decision makers use	❑ Standardization/interoperability (data sharing) of interface data – internal to the ranges and with external agencies ❑ Flexible, collaborative decision-making – regionally (localized and centralized) ❑ Improve generation and visualization of impact point and debris field ❑ Flexible, responsive options for destruct lines for customer needs ❑ Displays designed with human factors considerations ❑ Customized displays based on user physics ❑ Improved data visualization methods ❑ Review data at user locations ❑ Display data across range	❑ Improved confidence and response time ❑ Improve visualization ❑ Improve simulation ❑ Flexible, collaborative decision making nationally (localized and centralized) ❑ Minimize information overload – knowledge-base processing and display ❑ Commodity hardware (i.e., COTS) ❑ Display data across the network of ranges ❑ Remote displays ❑ Internet transport	❑ Flexible, collaborative decision making globally (localized and centralized) ❑ Global range with local execution of decisions and consolidation of resources ❑ Reduce man-in-the-loop decisions ❑ Launch authority has maintained sufficient cross-cued information through increased automation to match the ever-increasing real-time dynamics of Spaceport and Range operations ❑ Automated configuration and monitoring ❑ Seamless fusion of pertinent data ❑ Commodity hardware (i.e., COTS) ❑ Display data across the national network of ranges ❑ Remote displays ❑ Internet transport

Figure 24 Decision Making Support Subfunctions and Capability Goals Over Time

The following tables further address each subfunction by listing a number of quantifiable performance objectives, associated technical challenges and technical approaches that could be pursued to achieve the performance objectives. The tables also list a number of current projects underway that could enable the development or demonstration of technologies and systems that would address the technical challenges. Following each table is a description of the projects underway and the technology needs that remain to enable achieving the objectives.

Perform Risk Analysis: Preflight, flight, and landing

One subfunction is to perform risk analysis for preflight, flight, and landing operations. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the ability to do this in real-time.

Far-Term Objectives for Performing Risk Analysis			
Far-Term Objectives (FY 2016-2028)	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Integrated automated risk management and analysis globally ❑ Improve flexibility for managing diverse risk while minimizing impact to cost and schedule ❑ Integrated, automated models and processes of high fidelity and accuracy incorporating real-time tracking, sensing, and monitoring data ❑ Quantifiable (with high confidence) risk in a given environment ❑ Flight plan timelines decrease to 2 hours ❑ Continuous model execution ❑ Intelligent launch vehicles with increased reliability and maintainability	❑ Risk models use conservative parameters that sometimes limit availability of launch windows ❑ Uncertainty limitations include population densities, terrain, buildings, toxicology, atmospheric properties, and failure modes ❑ Reliability ❑ Consistency in models ❑ Confidence level (reduce uncertainty - better data for models and better models for data) ❑ Fidelity ❑ May have higher population densities along newer flight paths ❑ Traceability ❑ Customer-supplied data (vehicle failure and breakup modes, operational performance parameters) ❑ Integration and coordination between groups ❑ Faster, flexible models ❑ Solid rocket motors and storable fuels present higher risk ❑ Composite structures breakup characteristics still not well understood	❑ Improve standard environments definition such as populations and building location/types, better customer data on vehicles, etc. ❑ Improve Accuracy of models ❑ Validate models using real-time data and simulations ❑ Interoperability and common models across ranges	❑ 3-D dispersion models ❑ Assess toxic hazards of Advanced Composite Materials, hydrocarbon fuels, and mixtures of particulate and gaseous toxicants ❑ Joint Advanced Range Safety Systems (JARSS) – NASA/AF ❑ Advanced LIDAR

Additional Areas for Focused Development

Improve Accuracy and Interoperability of Models Across Ranges	**Validate Models Using Real-Time Data and Simulations To Produce Less Conservative Risk Models**	**Model Validation Testbeds**	**Sampling and Remote Sensing of Toxic Concentration Plume** *(size, shape, location, concentration, displacement, tracking)*	**Other**
• Validate model by comparing results with data from monitoring systems, testbeds, and databases	• Study and development of models for Advanced Composite Materials soon to be used	• Cost Benefit Analysis testbed for Range and Spaceport	• Eye-safe LIDAR systems for monitoring around populated areas	• Dynamic routing and risk assessment algorithms
• Improve standard environments definition (e.g., populations and building location/types, better customer data on vehicles)	• Solid Propellant Combustion Models for environmental concerns	• Process Analysis Technologies for an Intelligent Operations Testbed	• Microprobes	• Globalization of toxic decision models and processes
• Puff model theory validation	• A Methodology for Future Launch Vehicle Risk Analysis - A study of Unified High Order Risk Analysis Methods for Ascent and Reentry of RLV's	• Testbeds and simulations to be able to understand composite structures breakup characteristics	• Incident, forecast from incident site, receiver toxic and debris tracking data, now cast from data, and revise now cast from data	• Consideration of surface moisture

Maintain Real-Time Flight Safety Operations

Another subfunction is to maintain real-time flight safety operations. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the ability to do this in real-time.

Far-Term Objectives for Real-Time Flight Safety Operations			
Far-Term Objectives (FY 2016-2028)	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Data quickly available to all stakeholders (such as back to FAA to identify air lane restrictions – shorter restricted times may make airlines more receptive ❑ Seamless and fully integrated air and space traffic monitoring and control (Policy, Spaceport also) ❑ Schedule options not dependent on other users	❑ Distributed architecture (flight and ground systems) ❑ Level of integration with air traffic systems	❑ Standard protocols ❑ Create improved integration of "system of systems"	❑ Integrated National Aerospace Control Toolset (INACTS) - Phase 2 Small Business Innovation Research (SBIR). ❑ Toolset for integrated RLV/ELV operations in to the national airspace.

Additional Areas for Focused Development

Other Technologies for Real-Time Flight Safety Operations
• Integrate FAA and orbital tracking capabilities
• Common tools and applications available to all users
• Integrate real-time flight safety operations with scheduling tools

Maintain Situational Awareness During Real-Time Operations

Another subfunction is to maintain situational awareness. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the ability to do this in real-time.

Far-Term Objectives for Maintaining Situational Awareness During Real-Time Ops			
Far-Term Objectives (FY 2016-2028)	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Continuous updates of Safety COLAs ❑ Continuous updates of Mission assurance COLAs to produce integrated launch opportunities and windows ❑ Dynamic global situational awareness ❑ Multi-spacecraft simulations that predict time and location of potential congestions	❑ Perform "business case" trades for implementing range safety system designs - launch vehicle vice range system ❑ Size of exclusion area ❑ Number of intrusions ❑ Centralized collision avoidance ❑ Integrated satellite disposal planning ❑ Maneuver flexibility	❑ Knowledge capture ❑ Robust surveillance data (data supplied by the Surveillance function) ❑ Autonomous launch vehicle operations ❑ On-board situational awareness (SA) and preplanned actions ❑ Improved Air and Space traffic models ❑ Automated COLA Systems ❑ Improve forecasting and projection technologies	❑ Theater Undersea Warfare Initiative (TUSW) – Navy

Additional Areas for Focused Development

Other Technologies for Maintaining Situational Awareness During Real-Time Ops
• Develop business cases for evaluating system designs
• Improve air and space traffic models
• Automate COLA systems
• Multi-spacecraft simulations integrated with air and space traffic models
• Algorithms for multisensor data fusion and processing
• Underwater acoustical monitoring
• Artificial Intelligence for situational awareness forecasting to satisfy real-time data deficiencies

Fuse and Process Information Provided by the Other Range Functions and External Agencies

Another subfunction is to fuse and process information from other range functions and external agencies. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the ability to do this in real-time.

Far-Term Objectives for Fusing and Processing Information

Far-Term Objectives (2016-2028)	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ Seamless and integrated data flow and decision support tool with all stakeholders ❑ Ease of expandability and upgrade at minimal cost ❑ Dynamic/flexible airspace ❑ Less constraint oriented ❑ Support 21 simultaneous operations ❑ Fully autonomous systems that are knowledge-based (environmental and situational awareness) with ability to conduct level 3-4 fusion across a network of ranges ❑ Near continuous analysis and COA assessment	❑ Completeness of data ❑ Timeliness ❑ Integration with less technologically advanced support agencies ❑ Standardization ❑ Distributed architecture (flight and ground systems) ❑ Common platforms ❑ Open architectures ❑ Create improved integration of “system of systems” ❑ Interoperability (RCC currently helps to define standards)	❑ Replace obsolete processors ❑ Integration - distributed architecture (flight and ground systems) ❑ Improve coordination with external agencies (processes, procedures, and organizations) ❑ Mission life cycle continuity ❑ Distributed info and real-time integrated planning DST’s directly linked with other systems such as ground support, maintenance, etc. ❑ Standardize communications and data exchange protocols ❑ Modular plug and play range interfaces, fusion, and data processing bandwidth ❑ Common use of intelligent automated rule-based systems across a single range ❑ Data mining	❑ Standardize communications and data exchange protocols

Additional Areas for Focused Development

Other Technologies for Fusing and Processing Information
• Develop an "Integrated Airspace Concept of Operations" as one of the top 10 technology needs to help guide and prioritize technology requirements
• Improve coordination among agencies by developing integrated systems using modular plug and play range interfaces and automated decision support tools linked directly to each other
• Use of common rule-based systems across all ranges
• Reusable knowledge bases for problem solving
• Data capture and management from nonstandard systems
• Software engineering processes, methods, and techniques
• Traceability to policies, requirements, etc.
• Improved sensors

Present/Display Information for Decision Makers' Use

Another subfunction is to present and display information for use by decision makers. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the ability to do this in real-time.

Far-Term Objectives for Presenting and Displaying Information

Far-Term Objectives (FY 2016-2028)	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ Flexible, collaborative decision-making globally (localized and centralized) ❑ Global range with local execution of decisions and consolidation of resources ❑ Reduce man-in-the-loop decisions ❑ Launch authority has maintained sufficient cross-cued information through increased automation to match the ever-increasing real-time dynamics of Spaceport and Range operations ❑ Automated configuration and monitoring ❑ Seamless fusion of pertinent data ❑ Commodity hardware (i.e., COTS) ❑ Display data across the national network of ranges ❑ Remote displays ❑ Internet transport	❑ Completeness of information ❑ Data reduction ❑ Central "decision authority" for each range ❑ Standardization/ interoperability (data sharing) of interface data – internal to the ranges and with external agencies ❑ Timeliness ❑ Covers all support agencies ❑ Flexible range decision authority ❑ Human factors, ergonomics	❑ Replace obsolete hardware ❑ Flexible, collaborative decision making (localized and centralized) ❑ Data reduction and abstraction ❑ National range with local execution of decisions and consolidation of resources ❑ Interoperability ❑ Common interfaces ❑ Improve visualization ❑ Improve simulation ❑ Human Computer Interface/Interaction technology ❑ Biometrics ❑ Human Factors technology	❑ Advanced Checkout, Control, and Maint. System –NASA/KSC ❑ Command and Control Toolkit / Spaceport RangeNet (CCT Range Decision Support product line). ❑ Wallops Flight Facility Range Control Center Enhancement Initiative. ❑ Foundation Initiative 2010 - Test and Training Enabling Architecture (TENA) ❑ Biometric Research ❑ Intelligent Systems Program – NASA-Ames

Additional Areas for Focused Development

Software Engineering Processes, Methods, Techniques, etc.	**Integrated Intelligent Advisors** *(key to reducing human-in-the-loop decisions)*	**Multifunctional, Interactive Displays** *incorporating human factors, biometrics, and human computer interface technologies*
• Interoperability – the ability to exchange functionality and interpretable data between entities	• Perform tasks on the user's behalf	• Automated Reasoning (AR)
• Abstraction / Simplicity	• Train or teach users	• Intelligent Data Understanding (IDU)
• Extensibility - support for unforeseen uses and new requirements	• Help different users collaborate	• Human-Centered Computing (HCC)
• Symmetry - common interface for a wide range of components	• Monitor events and procedures	• Revolutionary Computing and Evolvable Systems
• Separation of Concerns - limits scope of changes as system evolves		
• Metadata - support for dynamic reconfigurability via self-descriptive services/information		
• Separation of hierarchies - layering		

Decision Making Support Technology Roadmap

The following technology roadmap (see Figure 25) displays the major technology areas, with time-phased recommendations regarding particular technologies to pursue in improving the ability of space launch and test ranges to support decision making.

Key technologies for decision making support include higher fidelity modeling and simulation based on enhanced data fusion and extraction capabilities, better integration with FAA space and air traffic management systems, and improved display capabilities.

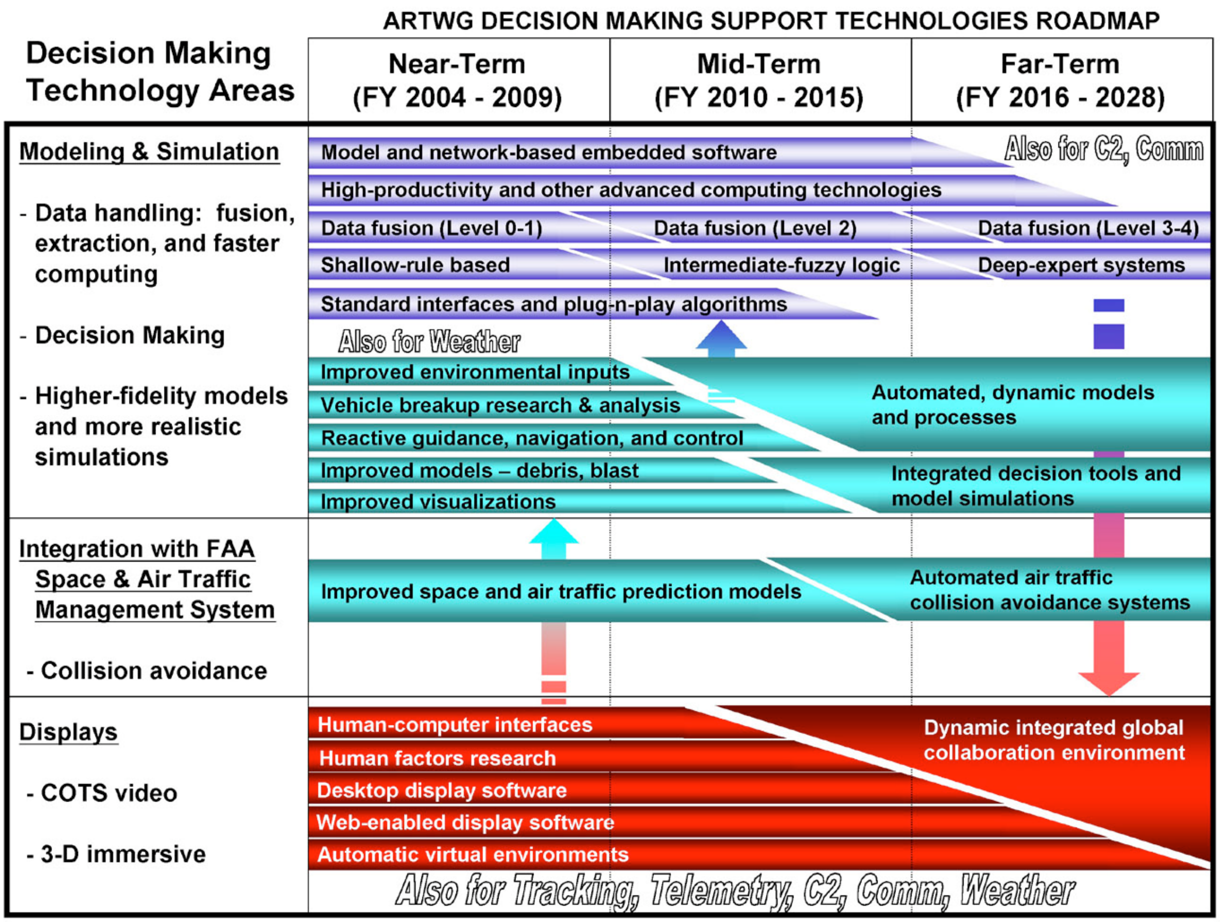

Figure 25 Technology Roadmap for Decision Making Support

PLANNING, SCHEDULING, AND COORDINATION OF ASSETS

PLANNING, SCHEDULING, AND COORDINATION OF ASSETS

The following top-level capability roadmap (see Figure 26) lists the qualitative goals for improved planning, scheduling, and coordination capabilities over time, as previously summarized with the other range functions.

ARTWG envisions capabilities in Planning, Scheduling, and Coordination of Assets (PSCA) evolving over time to increase automation and centrally address range activities on a broader and broader scale.

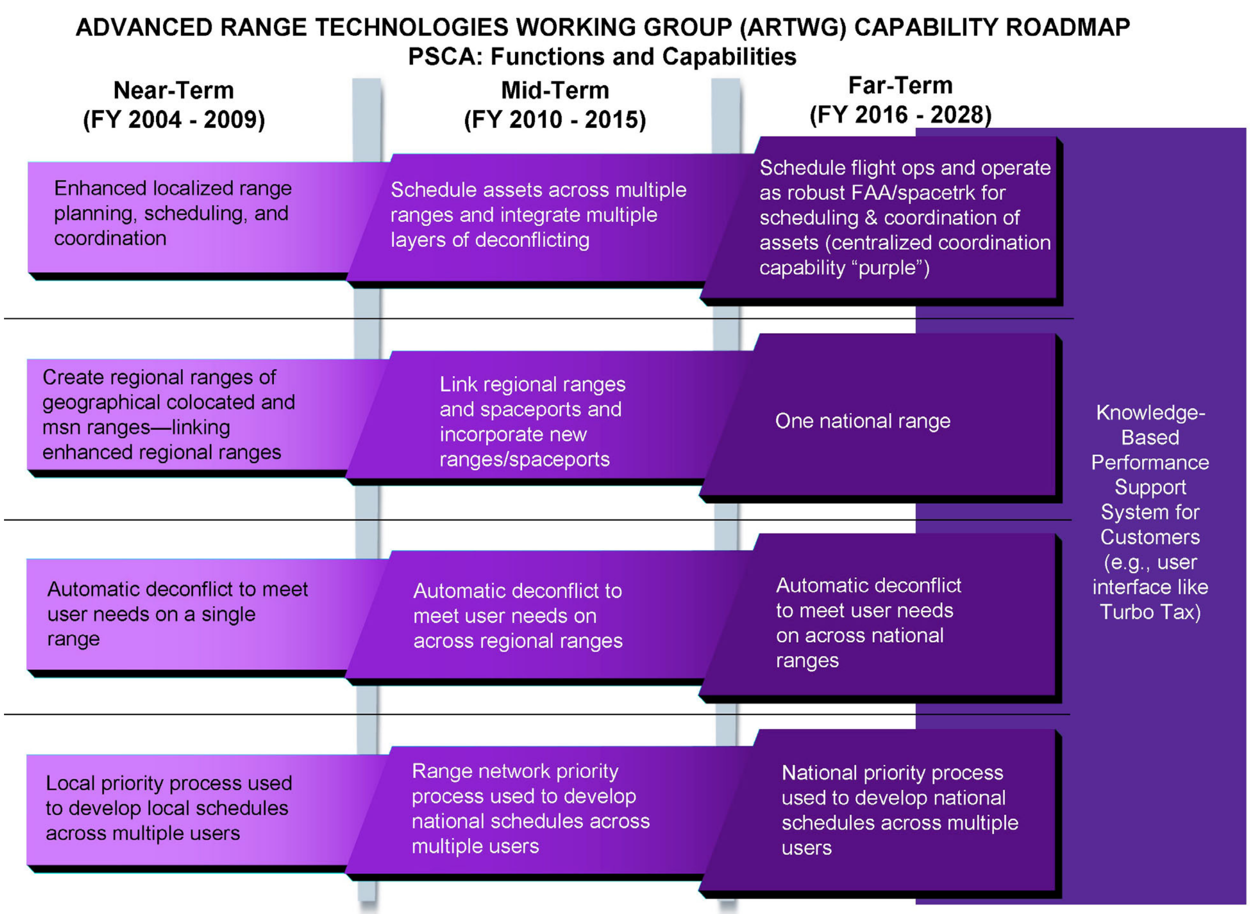

Figure 26 Capability Goals Over Time: Planning, Scheduling, and Coordination of Assets

The following subfunctions and capability goals (see Figure 27) were identified by the subgroup as elements of the scheduling and coordination of assets function:

Sub-Functions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Far-Term (FY 2016 - 2028)
Select courses of action (COA), Develop detailed plan, Test the plan, Coordinate the plan	❑ Automated rule-based system to develop and integrate plans within a range	❑ Semiautonomous (intelligent) rule-based system to develop (predictive), integrate, and coordinate plans (and re-plans) across multiple ranges with ability to perform level 2 fusion. ❑ Near real-time testing	❑ Continuous and responsive autonomous (knowledge-based) planning system that integrates and coordinates plans across network of ranges with ability to conduct up to Level 3-4 fusion. Incorporates environmental situation/ situational awareness. Optimized list of courses of actions (effects based planning) ❑ Faster than real-time testing
Develop User Specific Plan	❑ Enhanced planning support for the local range ❑ Electronic receipt, processing, generation, and dissemination of approved Universal Documentation System (UDS) information in a standard format, with range and range user organizations physically dispersed throughout the range and external to the range ❑ Complete automated transmission to internal and external customers ❑ Automated performance support systems for developing plans (e.g., "Turbo Tax" for space)	❑ Automated planning for common or baseline needs ❑ Manual planning to meet unique needs (e.g., test and evaluation operations) - unique mission needs are resolved in the planning stages	❑ Requirements electronically input system - user defines needs ❑ Autonomous plan generation ❑ Autonomous resource allocation/schedule
Allocate and Deconflict Assets (e.g., range and spaceport assets)	❑ Automated range asset allocation and notification by resource and operation number ❑ Automated identification of conflicts ❑ Multiple operators must be able to work multiple operations concurrently ❑ Interactively communicate scheduling information with range users	❑ Semiautonomous with human approval/ override	❑ Autonomous with human approval/override
Selective Release of Range Assets (when the asset is no longer to support the operation or launch window)	❑ Selective release of range assets, either individually or by groups, when no longer required to support an operation	❑ Automatically release with human override/approval within the regional range ❑ Begin to use continuously available systems	❑ Requirements electronically input system ❑ Automatic release ❑ Reduced use of dedicated systems

Sub-Functions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Far-Term (FY 2016 - 2028)
Lead/Support Range Interaction	❑ Interoperable connectivity within a region ❑ Enhanced regional coordination ❑ Centralized capability for coordinating assets ❑ Programs must be able to transition between ranges without requiring hardware/software configuration changes ❑ Programs must be able to transition between all national ranges without requiring hardware/software configuration changes ❑ Real-time interoperability with all other national ranges	❑ Interoperable connectivity across region ❑ Semiautonomous coordination across regions ❑ Common definition of assets	❑ No need for lead/support coordination ❑ A global range that is continuously available
Control Asset Allocations	❑ Centralized and automated management of internal planning and scheduling tasks. ❑ Complete automated transmission to internal and external customers ❑ Linked to Cheyenne Mountain for airspace availability	❑ Regional control	❑ Use national optimized resources to meet mission requirements - national/global control
Handle Inoperable Range Assets	❑ Connectivity with remote status and health displays ❑ Automatic exclusion of nonmission-capable assets from available inventory	❑ Automatic recognition of all systems within a region and display to operator ❑ Automatic call-up of options or automatic recon-figuration options for human selection	❑ Automatic recognition of all systems within national system ❑ Self-healing systems
Track and Report Asset Usage	❑ Automatically collect and export all utilization information to planning, programming, and budgeting processes	❑ Pay for assets used and analysis support ❑ Selectable, scalable (baseline requirements + additional support)	❑ Pay based on best national business case (e.g., fees, pay for use, or national tax/infrastructure) ❑ Capitalize and leverage resources that are free or omnipresent
Contribute in Developing the Long-Term Space-Lift Manifest Schedule	❑ Enhanced process	❑ Transition to regional control	❑ Centralized capability for coordinating assets ("purple people prioritization") for the nation

Figure 27 Planning, Scheduling, and Coordination of Assets Subfunctions and Capability Goals Over Time

The following tables further address each subfunction by listing a number of quantifiable performance objectives, associated technical challenges and technical approaches that could be pursued to achieve the performance objectives. The tables also list a number of current projects underway that could enable the development or demonstration of technologies and systems that would address the technical challenges. Following each table is a description of the projects underway, and the technology needs that remain to enable achieving the objectives.

Plan Use of Range Assets

One subfunction is to plan the use of range assets. This consists of selecting courses of action, developing a detailed plan, testing the plan, coordinating the plan, and developing a user-specific plan. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the ability to do this.

Far-Term Objectives for Planning Use of Range Assets			
Far-Term Objectives (FY 2016-2028)	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Continuous and responsive autonomous (knowledge-based) planning system that integrates and coordinates plans across network of ranges with ability to conduct up to Level 3-4 fusion. Incorporates environmental situation/situational awareness. Optimized list of courses of actions (effects based planning) ❑ Faster than real-time testing ❑ Requirements electronically input system - user defines needs ❑ Autonomous plan generation ❑ Autonomous resource allocation/schedule	❑ Make comprehensible information quickly and easily accessible at all levels ❑ Align users and range to communicate continuously ❑ Time to develop the range requirements - need to shorten the time to develop requirements ❑ Lack of knowledge of user community about the range ❑ Minimize errors caused by human element - automate where possible ❑ Smooth transition from integration/ planning phase to detail execution plan ❑ Integrate classified schedules and plans with unclassified schedule and plans	❑ Adaptable, graphical user interfaces ❑ Standardization of information requirements/reporting ❑ Automated, real-time status input ❑ Enterprise-wide scheduling/ planning applications ❑ Standard interfaces (COTS) for processing, transferring, displaying, and coordinating data/information ❑ Use COTS tool ❑ Timely processing, integration, transfer, display of data to support real-time operations ❑ "Turbo tax" for space - Knowledge-based system ❑ Standard list of range requirements to select from ❑ "Turbo tax" for space-- Knowledge-based system ❑ Software that eliminates routine activity ❑ Eliminate data entry - incorporate checks and balances in data entry process ❑ Procure system with hardware/ software that can handle both ❑ Provide all classified projects with information on unclassified projects	❑ Welcome software ❑ Artemis software ❑ Satellite Tool Kit (STK) ❑ NASA JSC Mission Control Center (MCC) architecture initiative ❑ NASA MSFC Ground Systems Dept distributed operations system for International Space Station (ISS) ❑ Data fusion and information extraction/mining techniques—being pursued at AFRL at Rome, NY, including /IFE (Information & Intelligence Exploitation), /IFEA (Information Fusion Technology), /IFEC (Multisensor Exploitation) ❑ Tera Hertz Operational Reachback (THOR) by DARPA/ATO ❑ Video Verification of Identity (VIVID) by DARPA/MTO ❑ FAA's Space and Air Traffic Management System (SATMS) ❑ Data Intensive Systems (DIS) by DARPA/IPTO ❑ NASA JSC MCC LAN Replacement project ❑ Automatic deconfliction engines for scheduling ❑ Basic knowledge-based system ❑ Workflow systems ❑ Single resource pool for all assets ❑ Ability to connect resources to plan ❑ Evolve command generation from rule-based, to fuzzy logic, to intelligent systems ❑ Intelligent command response logic with decision tree analysis ❑ Self-organizing and self-healing network technologies

Technologies that could contribute to improvements in planning for use of range assets are being pursued in the commercial sector for a wide variety of other applications.

Proposed Development Steps for Planning Use of Range Assets
• **<u>Leverage COTS development of planning and scheduling software and systems,</u>** including for example development of network access standards, graphical user interfaces, and intelligent expert systems.

Additional Areas for Focused Development

Other Technologies for Fusing and Processing Information
• Systems that seamlessly integrate planning with execution and a seamless interface with COTS
• Multifunctional, 2-D and 3-D graphical display and transmission of technical data
• Reusable knowledge bases for use in problem-solving situations
• Decision support tools
• Developing knowledge-based system for space launch and test ranges
• Highly efficient deconfliction engine
• Combined system with integrated schedule, integrated plan, deconfliction process, and detailed execution schedule

Schedule Use of Range Assets

Another related subfunction is to schedule the use of range assets. This consists of allocating and deconflicting assets (e.g., range and spaceport assets) and selective release of range assets (when the asset is no longer needed to support the operation or launch window). The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the ability to do this.

Far-Term Objectives for Scheduling Use of Range Assets

Far-Term Objectives (FY 2016-2028)	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ Autonomous with human approval/override	❑ Processes cumbersome and time consuming to complete ❑ Multiple requests for same equipment ❑ Multitudes of information ❑ Near-continuous scheduling - Two way interactive scheduling in near instantaneous modes ❑ Inconsistent philosophy of users sharing requirements to range	❑ Web-based distribution and integration of planning products with remote program partners ❑ Automated planning tools to select, schedule, balance, and verify vehicle resources ❑ Advancements from human-in-the-loop, to semiautonomous, to intelligent, autonomous system ❑ Enhanced capability of individual equipment (capacity to handle needs - scalable capabilities to meet growth) ❑ Automatic asset allocation based on priorities across the entire system beyond the local range ❑ Evolve command generation from rule-based, to fuzzy logic, to intelligent systems ❑ Massive automatic deconfliction scheduling systems ❑ Modeling tools of entire system ❑ Sorting of critical items to support the scheduling of items causing most problems within the schedule ❑ Advanced algorithms to focus on only segments that are impacted by the mission and not entire system ❑ Interface with “Turbo-Tax” style front end ❑ Standardized approach for defining requirements	❑ FAA’s Space and Air Traffic Management System (SATMS) ❑ NASA MSFC Ground Systems Dept distributed operations system for ISS ❑ NASA JSC MCC architecture initiative ❑ DoD Transformational Comm System (TCS) for satellite laserlinks and software-reconfigurable network ❑ Commercial Internet backbone service providers (e.g., UUNET) ❑ Missile Defense Agency BMC3 ❑ Mobile adhoc network technology (MANET) by Internet engineering task forces ❑ Automatic deconfliction engines for scheduling (e.g., Quantum Leap Innovations) ❑ Basic knowledge-based system ❑ Workflow systems ❑ Quantum Leap ❑ Frontier Technologies ❑ Scheduling deconflicting tools ❑ JPL turbo codes ❑ JSC-Ames Information Sharing Protocol ❑ FAA Commercial Space Transportation CONOPS
❑ Requirements electronically input system ❑ Automatic release ❑ Reduced use of dedicated systems	❑ Integration with scheduling software ❑ Automatic deconfliction	❑ Turbo-tax” style UDS process - Knowledge-based system ❑ Detect and resolve conflicts at input ❑ Advanced scheduling ❑ Detect, resolve, and advise ❑ Scheduling deconflicting tools ❑ Tool to support integrating multiple requirements and priorities with human override/approval	❑ FAA’s Space and Air Traffic Management System (SATMS) ❑ Quantum Leap ❑ Frontier Technologies ❑ Automatic deconfliction engines for scheduling (e.g., Quantum Leap Innovations) ❑ Basic knowledge-based system ❑ Workflow systems

Technologies and approaches that could improve the scheduling of range assets are also being pursued in the commercial sector for a variety of applications.

Proposed Development Steps for Scheduling Use of Range Assets
• **Leverage COTS development of planning and scheduling software and systems,** including for example development of network access standards, graphical user interfaces, and intelligent expert systems.

Additional Areas for Focused Development

Other Technologies for Fusing and Processing Information
• Advanced data mining technologies
• Autonomous, self-learning systems
• Better algorithms
• Data fusion and information extraction/mining techniques - being pursued at AFRL at Rome, NY, including /IFE (Information and Intelligence Exploitation), /IFEA (Information Fusion Technology), /IFEC (Multisensor Exploitation)
• Data processing and storage algorithms for massive amounts of data
• Enable “fine-grain” fusion of physical and information processes
• Intelligent command response logic with decision tree analysis
• Learning databases
• MEMS (micro electromechanical systems)
• Multifunctional, 2D and 3D graphical display and transmission of technical data
• On-board satellite fusion of data to reduce ground system processing
• Self-organizing and self-healing network technologies
• Standards for display hardware and software
• TurboTax-like UDS process - Knowledge-based system

Coordinate Use of Range Assets

The third major subfunction is to coordinate the use of range assets. This includes lead/support range interaction, controlling range asset allocations, handling inoperable range assets, tracking and reporting asset usage (i.e., actuals for financial management), and contributing to developing the long-term spacelift manifest and schedule. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the ability to do these subfunctions.

Far-Term Objectives for Coordinating Use of Range Assets

Far-Term Objectives (FY 2016-2028)	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ Automatic recognition of all systems within national system ❑ Self-healing systems	❑ Have enough redundancy and coverage	❑ Scalable and flexible infrastructure ❑ Leverage regional and national assets	❑ Under assessment
❑ No need for lead/support coordination ❑ A global range that is continuously available	❑ Getting community together (no parochialism) ❑ Interoperability of systems	❑ Network development—systemic upgrades of infrastructure ❑ Standard interfaces for processing, transferring, displaying, and coordinating data/information ❑ Systems that incorporate standard, expandable, plug-and-play, off-the-shelf technologies ❑ Common interfaces/protocols ❑ Adaptable/flexible interfaces ❑ Plug-and-play capabilities ❑ Standardized systems	❑ Systems (HPCS) by DARPA/IPTO ❑ Adaptive and Reflective Middleware Systems (ARMS) by DARPA/IPTO ❑ Network Embedded Software Technology (NEST) by DARPA/IEO ❑ THOR ❑ Front-end boxes connected to equipment to gather and share standardized interface/information (e.g., SLRSC at WR/ER) ❑ FAA Commercial Space Transportation CONOPS ❑ JPL turbo codes ❑ JSC-Ames Information Sharing Protocol ❑ FAA SATMS ❑ VIVID

Far-Term Objectives for Coordinating Use of Range Assets			
Far-Term Objectives (FY 2016-2028)	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Use national optimized resources to meet mission requirements - national/global control ❑ Centralized capability for coordinating assets ("purple people prioritization") for the nation	❑ Having enough assets/capacity ❑ Pooling the resources to accommodate the need ❑ Detecting when there is a conflict	❑ Scalable, responsive assets ❑ Automatically configurable ❑ Automated planning tools to select, schedule, balance, and verify vehicle resources ❑ Advancements from human-in-the-loop, to semiautonomous, to intelligent, autonomous system ❑ Centralized data bases of asset availability and capability ❑ Advanced scheduling algorithms ❑ Adaptive, expert system to assemble data into real-time situational awareness information ❑ Evolve command generation from rule-based, to fuzzy logic, to intelligent systems ❑ Detect and resolve conflicts at input ❑ Integrating data from multiple, disparate sources to support the automated generation of potential courses of action ❑ Automated sensor data archive retrieval, trend analysis, and recommended course of actions	❑ Navy and AFRL research into phased array antennas ❑ Flexible digital payloads for reconfigurable phased array antennas, digital beamforming, digitally programmable channel assignments ❑ Multibeam Antennas - advanced multibeam phased array technology – at NASA GRC ❑ Reconfigurable Aperture Program (RECAP) by DARPA/SOP ❑ Innovative Space-Based Radar Antenna Technology (ISAT) by DARPA/SPO ❑ Airborne Communications Node (ACN) by DARPA/IXO ❑ Improved TDRSS satellite communication and bandwith ❑ NASA MSFC Ground Systems Dept distributed operations system for ISS ❑ NASA JSC MCC architecture initiative ❑ DoD Transformational Comm System (TCS) for satellite laserlinks and software-reconfigurable network ❑ DoD's Multisensor Command and Control Aircraft (MC2A) ❑ DoD's Multisensor Command and Control Constellation (MC2C) ❑ DoD's Joint Tactical Radio System (JTRS) ❑ Automatic deconfliction engines for scheduling (e.g., Quantum Leap Innovations) ❑ Basic knowledge-based system ❑ Workflow systems ❑ NASA JSC MCC architecture initiative ❑ NASA MSFC Ground Systems Dept distributed operations system for ISS ❑ FAA's space and air traffic management system (SATMS) ❑ Frontier Technologies ❑ Scheduling deconflicting tools
❑ Pay based on best national business case (e.g., fees, pay for use, or national tax/infrastructure) ❑ Capitalize and leverage resources that are free or omnipresent			

DoD is pursuing a variety of technologies to improve its ability to ensure information dominance during conflicts by pursuing network-centric warfare approaches and capabilities. Many of these approaches could be leveraged to improve the coordination of range assets across broad geographic areas and across multiple organizations.

Proposed Development Steps for Coordinating Use of Range Assets
• **Advocate Flexible, Scalable, and Adaptable Interfaces for Plug-and-Play Sensor and Algorithm Integration** to enable automated detection of conflicts at input, generation of potential courses or action, resource balances, and schedule deconfliction. • **Leverage Research in Intelligent Expert Systems** to integrate data from multiple sources to support development of systems that can provide real-time situational awareness regarding range assets.

Additional Areas for Focused Development

Other Technologies for Fusing and Processing Information
• Automated problem analysis of historical sensor data
• Automated sensors to tie into network
• Autonomous, comm infrastructure
• Combined system with integrated schedule, integrated plan, deconfliction process, and detailed execution schedule
• Common network protocols for data sharing and communications
• Decrease size, weight, power requirements, latency of access, failure rate, and cost of data storage
• Instantaneous scheduling for satellites
• Intelligence information and fuzzy logic to support real-time development of courses of action while operations are ongoing
• Nano-technology (e.g., carbon nano-tubes for ceramic phased arrays)
• New collecting sensors
• Phased arrays capable of operating at higher frequencies
• Reusable knowledge bases for use in problem-solving situations
• Self-repairing/maintaining equipment
• Standard interfaces to enable development and use of plug and play data fusion algorithms
• System that seamlessly integrates planning with execution and a seamless interface with COTS
• Vertically interconnected technologies used simultaneously

Planning, Scheduling and Coordination of Assets (PSCA) Technology Roadmap

The following technology roadmap (see Figure 28) displays the major technology areas, with time-phased recommendations regarding particular technologies to pursue in improving the ability of space launch and test ranges to plan, schedule, and coordinate the use of range assets.

Key technologies for scheduling and coordination of range assets include integrated software tools to evolve from rule-based to knowledge-based expert systems and database systems to enable autonomous scheduling and deconfliction.

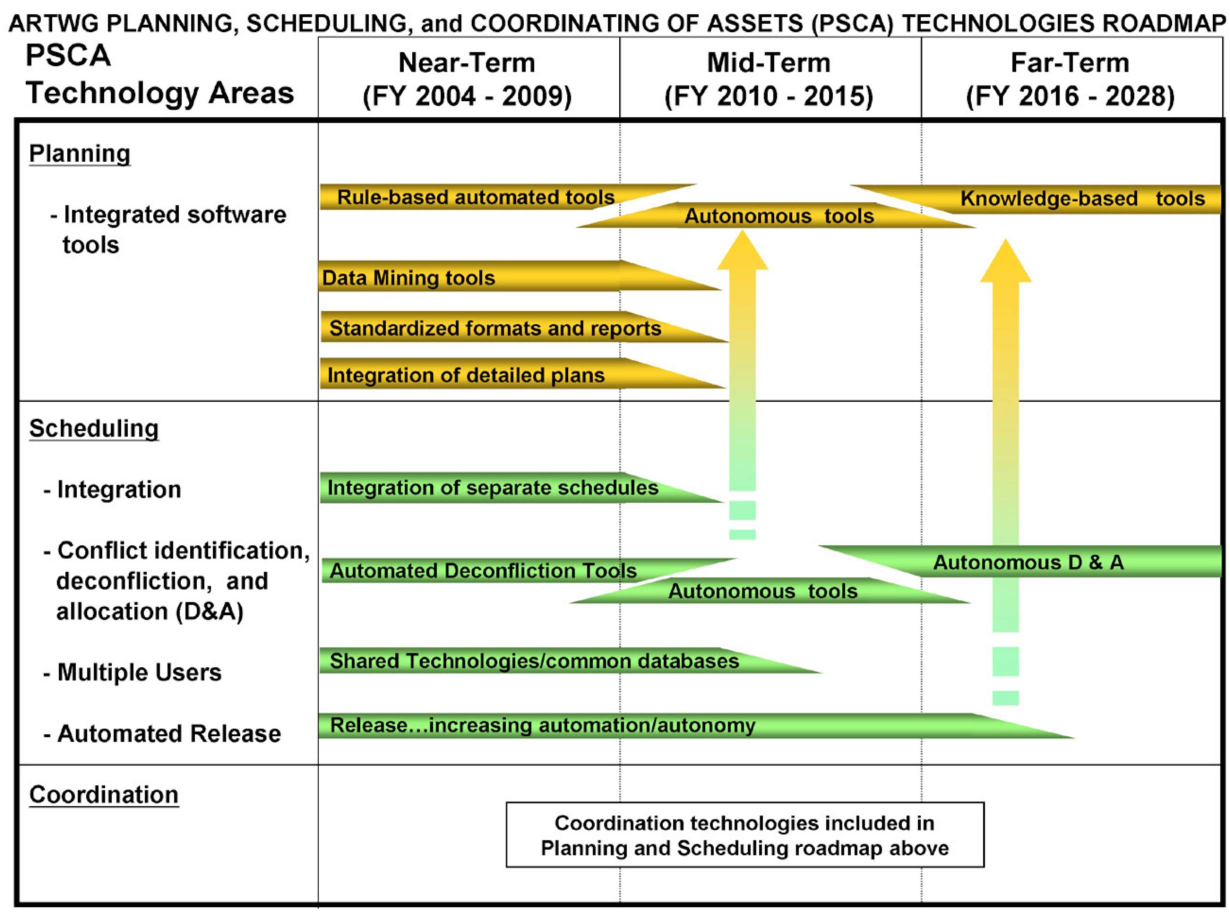

Figure 28 Technology Roadmap for Planning, Scheduling, and Coordination of Assets

WEATHER MEASUREMENT AND FORECASTING

WEATHER MEASUREMENT AND FORECASTING

The following top-level capability roadmap (see Figure 29) lists the qualitative goals for improved range weather measurement and forecasting capabilities over time, as previously summarized with the other range functions.

ARTWG envisions capabilities in Weather Systems evolving over time toward centralized hubs for forecasting and technology transition, based on improvement of sensors and models.

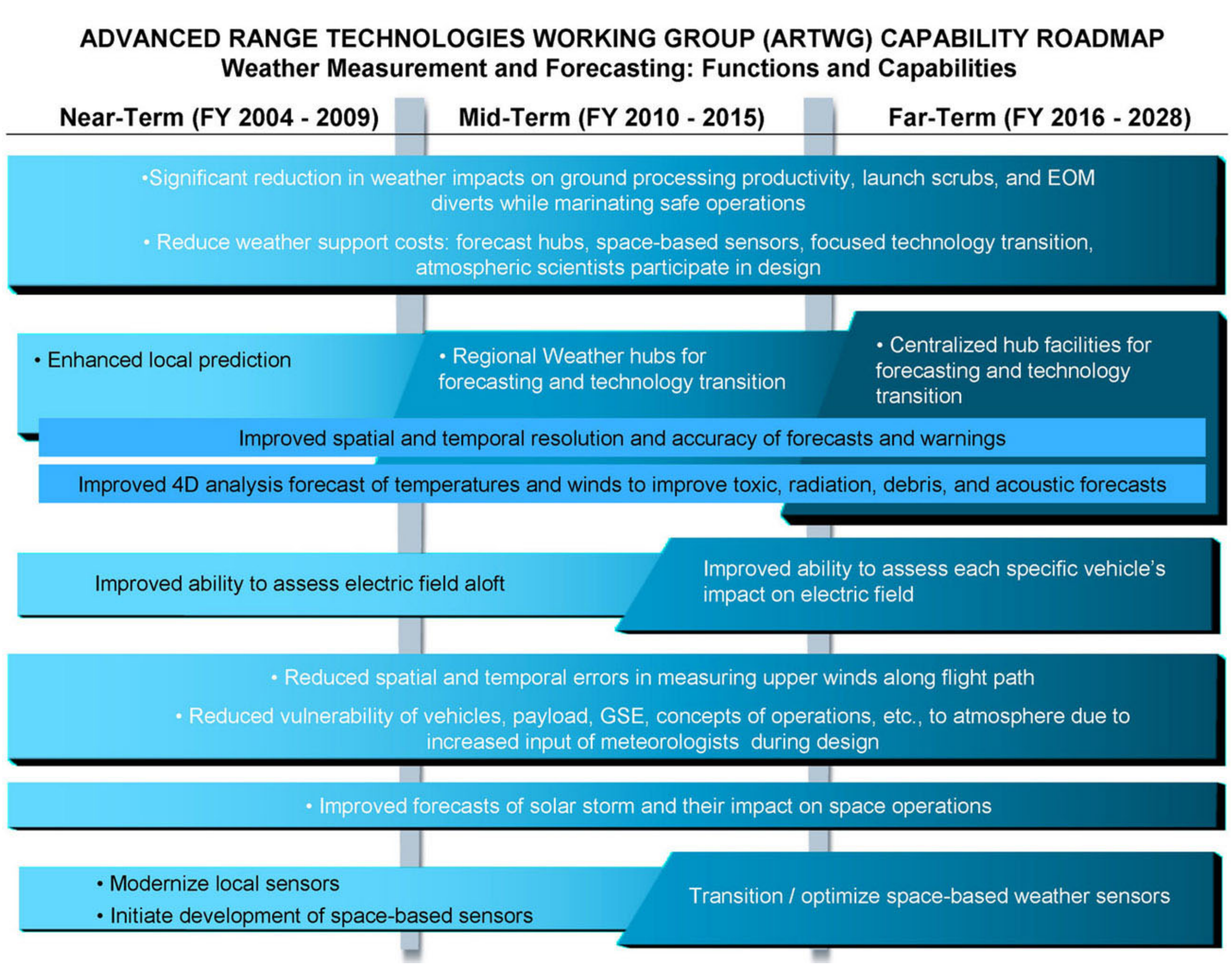

Figure 29 Capability Goals Over Time: Weather Measurement and Forecasting

The following subfunctions and capability goals (see Figure 30) were identified by the subgroup as elements of the weather function:

Subfunctions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Long-Term (FY 2016 - 2028)
Forecasts for Spaceport Operations 1. Improved Weather Warnings (lightning within 5 nautical miles (NM); winds >35 knots; hail; extreme temps etc.) with >/= 30 minutes lead time *FAR=False Alarm Rate* *POD=Probability of Detection* *DLT=Desired Lead Time*	❑ Location Error: 4 NM ❑ FAR: 35% ❑ POD: 85% ❑ Met DLT: 80% ❑ End time: <40 minutes too long (end warning when threat gone)	❑ Location error: 3 NM ❑ FAR: 20% ❑ POD: 87% ❑ Met DLT: 85% ❑ End time: <20 minutes too long	❑ Location Error: 2 NM ❑ FAR: 10% ❑ POD: 90% ❑ Met DLT: 90% ❑ End time: <10 minutes too long
2. Improved Catastrophic Weather Warnings - tornadoes, convective and non-convective winds >60 knots, hail >1/2 inch with >/= 15 minutes lead time; freezing rain; blizzard with > 24 hours lead time	❑ Location Error: 40 NM ❑ FAR: 50% ❑ Met DLT: 80% ❑ Timing Error: +/- 3 hours	❑ Location Error: 10 NM ❑ FAR: 30% ❑ Met DLT: 85% ❑ Timing Error: +/- 2 hours	❑ Location Error: 5 NM ❑ FAR: 20% ❑ Met DLT: 90% ❑ Timing Error: +/- 1 hour
3. Improved 2 hour Forecasts of Location of Convective Weather Cells	❑ <10 mile error ❑ >80% of forecasts	❑ <5 mile error ❑ >85% of forecasts	❑ <2 mile error ❑ >90% of forecasts
4. Improved Communication of Warnings	❑ Received within 5 minutes of issue ❑ 99% correctly and easily understood by customers	❑ Received within 3 minutes of issue ❑ 100% correctly and easily understood by customers	❑ Received within 1 minute of issue ❑ 100% correctly and easily understood by customers

Subfunctions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Long-Term (FY 2016 - 2028)
Launch Commit Criteria Evaluation 1. Improved Lightning Launch Commit Criteria (LLCC) *ABFM = Airborne Field Mill*	❑ Reduce unneeded LLCC scrubs from 75% to 60% ❑ Estimate electric field to within factor of 5 to 99% confidence ❑ Remotely measure meteorological conditions creating electric charge	❑ Reduce unnecessary scrubs due to LLCC to 30% ❑ Estimate electric field to within factor of 3 to 99% confidence ❑ Directly measure electric field along/near flight path (ABFM) ❑ Vehicles hardened to electric charge/discharge	❑ Reduce unneeded scrubs due to LLCC to <15% ❑ Estimate electric field to within factor of 1.5 to 99% confidence ❑ Remotely measure electric charge along/near flight path ❑ LLCC with thresholds as function of vehicle
2. Improved Upper Air Winds	❑ Realistic vertical resolution requirements ❑ Ground-based profilers as sole source of upper winds (no balloons) ❑ Automated Quality Control integrated into Signal Processing Algorithm	❑ Update steering commands at L-5 Minutes ❑ Improve profiler vertical resolution to take advantage of L-5 steering update	❑ Space and/or vehicle-based profilers to supplement ground based profilers
3. Improved Low-Level Wind Forecasts for winds > 20 knots	*Vector wind accuracies within*: ❑ 12 Knots at L - 10 Hours ❑ 8 Knots at L - 5 Hours ❑ 5 Knots at L - 0. 5 Hour	*Vector wind accuracies within:* ❑ 8 Knots at L – 10 Hours ❑ 6 Knots at L - 5 Hours ❑ 3 Knots at L – 0. 5 Hour	*Vector wind accuracies within:* ❑ 6 Knots at L - 10 Hours ❑ 3 Knots at L - 5 Hours ❑ 2 Knots at L – 0.5 Hour

Subfunctions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Long-Term (FY 2016 - 2028)
Toxics, Radiation, Debris, and Blast Improved 4D Predictions of Toxic and Radiation Concentration; Debris Impact Points; and Acoustic Damage	❑ Toxic Concentration Accuracy as F (Chemical, Distance, Observed and Forecast) = 90% with 1-km resolution ❑ Debris and Radiation Fallout Accuracy (Observed and Forecast) = 90% with 1-km resolution ❑ BLAST casualties with 90% accuracy ❑ Update window characterization and population files in blast model ❑ Acquire measured turbulence values from 915 MHz profilers and mini-sodars ❑ Migrate to 3-D puff dispersion model ❑ Modify debris and blast models to accept forecast atmospheric parameters ❑ Update vehicle breakup characterization and debris categories	❑ Toxic Concentration Accuracy as F (Chemical, Distance, Observed and Forecast) = 95% with 0.75-km resolution ❑ Debris and Radiation Fallout Accuracy (Observed and Forecast) = 95% with 0.75-km resolution ❑ BLAST casualties with 95% accuracy ❑ Improve resolution and frequency of 3-D wind and temperature measurements ❑ Migrate to higher resolution, more accurate mesoscale prediction models, and dispersion, blast and debris models	❑ Toxic Concentration Accuracy as F (Chemical, Distance, Observed and Forecast) = 99% with 0.5-km resolution ❑ Debris and Radiation Fallout Accuracy (Observed and Forecast) = 99% with 0.5-km resolution ❑ BLAST casualties with 99% accuracy ❑ Remotely measure location and toxic concentration in abort clouds for input to improved dispersion models ❑ Improved climatology of short-term variance of atmospheric properties for use in risk models

Subfunctions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Long-Term (FY 2016 - 2028)
Recovery Forecasts Improved 90-Minute Forecasts of: 1. Recovery Site Ceilings, Visibilities, Winds and Convective Weather	*Accuracies met > 95% of time*: ❑ Cloud Base: within 400 ft ❑ Visibility: within ½ mile ❑ Peak Wind Speed: within 5 knots ❑ Peak Wind Direction: within 20 degrees	*Accuracies met > 95% of time*: ❑ Cloud Base: within 200 ft ❑ Visibility: within ¼ mile ❑ Peak Wind Speed: within 3 knots ❑ Peak Wind Direction: within 10 degrees	*Accuracies met > 95% of time*: ❑ Cloud Base: within 100 ft ❑ Visibility: within 1/8 mile ❑ Peak Wind Speed: within 2 knots ❑ Peak Wind Direction: within 5 degrees
2. Reentry Atmosphere Density, Temperature, and Winds	*Mesosphere: 90 Min Forecast* *Accuracy* *Resolution* *Horiz/Vert* ❑ Temp 5 C 50/1km Wind 10 m/s 50/1 km ❑ Density 5% 50/1 km ❑ Pressure 5% 50/1 km ❑ Hazards: Identify location of strong Inversions with 3-km vertical resolution	*Mesosphere: 90 Min Forecast* *Accuracy* *Resolution* *Horiz/Vert* ❑ Temp 3 C 25/0.3km ❑ Wind 5 m/s 25/0.3km ❑ Density 3% 25/0.3km ❑ Pressure 3% 25/0.3km ❑ Hazards: Measure small scale: 1. Density Gradients: 3%/ km 2. Wind Shears: 20/m/s/ km at 3-Km resolution	*Mesosphere: 90 Min Forecast* *Accuracy* *Resolution* *Horiz/Vert* ❑ Temp 1 C 10/0.1 km ❑ Wind 2 m/s 10/0.1 km ❑ Density 1% 10/0.1 km ❑ Pressure 1% 10/0.1 km ❑ Hazards: Measure small scale: 1. Density Gradients: 1%/ km 2. Wind Shears: 5/m/s/ km at 0.1-km resolution

Subfunctions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Long-Term (FY 2016 - 2028)
Infrastructure and People			
1. Data automatically sensed, quality checked, archived, analyzed, displayed, transformed into forecasts and warnings, and communicated to customers	❑ Requirements for forecaster intervention/labor hours reduced: 35%	❑ Requirements for forecaster intervention/ labor hours reduced: 70%	❑ Requirements for forecaster intervention/ labor hours reduced: 90%
2. Forecast hubs serving multiple spaceports	❑ Forecast hubs supporting 20% of space program	❑ Forecast hubs supporting 50% of space program	❑ Forecast hubs supporting 80% of space program
3. Maximum use of space-based weather sensors to service multiple ranges/ spaceports	❑ Plan replacement of ground-based sensors with space-based sensors	❑ Replace 10% ground-based sensors with space-based sensors	❑ Replace 40% ground-based sensors with space-based sensors
4. Technology transition unit(s) to transition needed weather technology into operations	❑ Combined ER/WR technology transition unit	❑ Combined technology transition unit for ER, WR, Wallops (all Federal Gov't spaceports)	❑ Combined technology transition unit for all US spaceports/ranges (all US spaceports)
5. Advanced degree atmospheric scientists at space system design nodes	❑ One staff meteorologist at Space and Missile Center (SMC) and other space systems design nodes	❑ Three staff meteorologists at SMC and other space systems design nodes	❑ Staff meteorologists assisting all spacecraft and operations concept design nodes

Subfunctions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Long-Term (FY 2016 - 2028)
Space Forecasts			
1. Improved Solar Events Occurrence Forecasts –flare/x-ray level, filament eruption, CME, etc. Help mitigate and exploit effects of space environment on SATCOM, radar, and HF Communications	❑ Category 10% ❑ Timing +/- 18 hours ❑ False Alarm rate 40%	❑ Category 20% ❑ Timing +/- 12 hours ❑ False Alarm Rate 25%	❑ Category 35% ❑ Timing +/- 6 hours ❑ False Alarm Rate 15%
2. Improved Solar Events Effects Forecasts Short Term: Particle events, ionospheric effects, polar cap absorption events, etc. Help mitigate and exploit effects on spacecraft operations and high-altitude aircraft missions including satellite disorientation, false sensor readings, spacecraft charging/damage, degraded communication over poles, and radiation exposure to astronauts and aircrews	❑ Category/Flux 10% ❑ Timing +/- 30 minutes ❑ Duration 24 hours ❑ False Alarm Rate 25%	❑ Category/Flux 20% ❑ Timing +/- 15 minutes ❑ Duration 12 hours ❑ False Alarm Rate 15%	❑ Category/Flux 35% ❑ Timing +/- 10 minutes ❑ Duration 6 hours ❑ False Alarm Rate 10%
3. Improved Solar Events Effects Forecasts—Long Term: geomagnetic events, etc. Mitigate/exploit effects on spacecraft operations and communications such as spacecraft charging and drag, space track errors, launch trajectory errors, radar interference, and radiation hazards	❑ Category/Maximum 10% ❑ Timing +/- 16 minutes ❑ Duration 24 hours ❑ False Alarm Rate 25%	❑ Category/Maximum 20% ❑ Timing +/- 3 minutes ❑ Duration 12 hours ❑ False Alarm Rate 15%	❑ Category/Maximum 35% ❑ Timing +/- 1 minute ❑ Duration 6 hours ❑ False Alarm Rate 10%

Figure 30 Weather Measurement and Forecasting Subfunctions and Capability Goals Over Time

The following tables further address each subfunction. Objectives are the long-term (FY 2016-2028) performance objectives from Figure 30 above. Also listed are the associated technical challenges and technical approaches that could be pursued to achieve the performance objectives. The tables also list a number of current projects underway that could enable the development or demonstration of technologies and systems that address the technical challenges. Following each table is a description of the projects underway and the technology needs that remain to enable achieving the objectives.

Forecasts for Spaceport Operations and Recovery

The first subfunction in advancing weather support to launch and test ranges is improving forecasts for spaceport operations, especially vehicle and payload processing, and vehicle deorbit and recovery. The following table summarizes the specific objectives (FY 2016-2028), technical challenges, approaches, and current technology projects under development to address forecasts for spaceport operations and recovery.

Far-Term Objectives for Forecasting Weather			
Objectives	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
Safely Reduce Labor Hours Lost Due to Weather Warnings 1. Improved Weather Warnings Lead Time: < 30 Minutes ❑ FAR: 10% ❑ POD: 92% ❑ Met DLT: 90% ❑ End time: <10 Minutes Too Long (end warning when threat gone) 2. Improved Catastrophic Weather Warnings Lead Time: < 30 Minutes ❑ Location Error: 5NM ❑ FAR: 30% ❑ Met DLT: 92% ❑ Timing Error: +/- 1 hour 3. Improved 30-120 Minute Forecasts of Convective Weather Location ❑ <2 mile error ❑ >90% of forecasts **Safely Reduce EOM Diverts to Alternate Landing Site Due to Forecast Uncertainty** 1. Improved 90-Minute Forecasts at Recovery Sites. Accuracies met > 95% of time: ❑ Cloud Base: within 100 ft ❑ Visibility: within 1/8 mile ❑ Peak Wind Speed: within 2 knots ❑ Peak Wind Direction: within 5 degrees 2. Improved 30-120 Minute Forecasts of Convective Weather Location ❑ <2 mile error ❑ >90% forecasts **Improved Communication of Warnings:** ❑ Received within 3 minutes of Issue ❑ 100% correctly and easily understood by customers	❑ Improve quantity and quality of data available to feed numerical weather models and local forecast techniques	❑ **DATA** Improve temporal and spatial resolution and accuracy of data input into models	❑ Buoy sensors: Profilers for wind, temperature and moisture; field mills ❑ Improved remote sensing and understanding of cloud microphysics ❑ River Sensors—Salinity, Temperature vs. Water Depth ❑ Soil Moisture Sensor Networks using radar from towers or GPS ❑ GPS-based Total Precipitable Water Sensors 1. Regional/Statewide Meso-network for Mesoscale models 2. Local Micro-network for local Thunderstorm Forecasts ❑ UAVs to provide temporal and spatial (4D) temperature, moisture, winds, cloud particle size and concentration ❑ Remote sensors (profilers and satellites) to provide 4D observed thermodynamic (temperature, moisture) and wind data with sufficient spatial and temporal resolution, and accuracy to feed models ❑ 4D assimilation of data from diverse sources and nonstandard times ❑ MDCRS: Water vapor data from sensors on commercial and private aircraft ❑ Improved observation of turbulence and windshear
	❑ Improve Accuracy of >2 day Forecasts (Global Models**)**	❑ **MODELS** Improve Accuracy, Resolution, and Availability of Numerical Weather Models—Analysis, Convective, Nowcast, Mesoscale, and **Global**	❑ Global Model: Spatial Resolution 50-100 km; Forecast Length: 240-720 km ❑ Blended Systems that weight**:** 1.Numerical Models (Analysis, Now cast, Convective Scale, Mesoscale, Global); 2.Extrapolation Techniques; and 3. Physically Based Rules (heuristic) —all able to be modified by forecaster (examples**:** A. NCAR Auto-Nowcaster; B. NIMROD (UK) (lesser capability first 2 hours: extrapolate satellite & radar; 6 hours: Models; 2-6 hours: Mix) ❑ *'*Blended' also applies to 4 bullets below*:* ❑ Weather Research & Forecast Model (WRF) ❑ Ocean Models: Improved measurements/ resolution of salinity and temperature as function of depth. Measurement of ocean currents, eddies, etc.
	❑ Improve accuracy of 1/2 –2 day forecasts to improve weather-critical operational planning decisions	❑ Increase temporal and spatial accuracy of **Mesoscale** Model forecasts	❑ Mesoscale models with: Spatial Resolution: 10-20 km Forecast Length: 6-84 Hours Coverage: Nested-Regional-Local Run Time: < 1/4 Forecast Length ❑ Ensemble Mesoscale Models
	❑ Improve accuracy of 2-12 hour forecasts for operations requiring longer exposure times	❑ Improve temporal & spatial accuracy of Mesoscale and **Convective Scale** Models	❑ Convective Scale Models with: Spatial Resolution: 1- 5 km Forecast Length: 1.0 –2.0 Hours ❑ Warning Decision Support System (WDSS II)

Far-Term Objectives for Forecasting Weather			
Objectives	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
	EOM/Recovery ❑ 1. Improve mesosphere measurements and models for reentry and data assimilation techniques	❑ 1. Network of surface, satellite, and direct measurements of Mesosphere Meteor Radars, Low Frequency radars, etc.). Archive and analyze data	❑ 1A. TIME-D mission with SABER (Sounding of Atmosphere using Broadband Emission Radiometry). 1B. Aura Mission in 2004 with (a) HIRDLS (High Resolution Dynamics Limb Sounder); (b) Microwave Limb Sounder. 1C. MIPAS (Michelson Interferometer for Passive Atmospheric Sounding). 1D. WACCM (Whole Atmosphere Climate Community Model) from surface to 600 km.) 1E. *Data assimilation techniqu*es to take full advantage of synergy possible with proper integration of these diverse data sources**.**
	❑ 2. Improve measurements of winds along descent flight path	❑ 2. Improve high resolution sensors measuring winds along descent flight path	❑ 2. Lidars and Hypersodars for high-resolution slant path winds just prior to landing
	❑ 3. Improve accuracy of 75-90 minute recovery forecasts	❑ 3. Improve temporal and spatial accuracy of Convective Scale Model forecasts	❑ 3. Warning Decision Support System (WDSS II)
	❑ 4. Understand causes of and methods to measure and forecast upward lightning (Sprites, Elves, Blue Jets, etc.)	❑ 4. Increase observations of and research into upward lightning - including its causes and its current characteristics	❑ 4**.** Data gathering programs to understand characteristics (energy, altitudes, frequency, etc.) of upward lightning. Problem – these programs are only sparsely funded,)
	Ground Processing ❑ 1. Improve accuracy of and temporal and spatial resolution of Weather Advisories and Warnings: time of first/last lightning; convective winds >35 knots with 2 minutes lead time; hail; tornadoes; freezing and frozen precipitation	❑ Forecast location, time, strength, and movement of thunderstorm development ❑ Forecast time of first/last lightning	❑ Decision algorithms to identify and forecast severe weather ❑ Decision aids to alert forecaster to impeding hazardous phenomena ❑ Improve measurements and models of Microphysics of individual convective cells ❑ Convective Scale Models (see above)
	❑ 2. Design methods to quickly, accurately, and clearly communicate vital weather information to workers and supervisors in numerous, diverse, and sometimes remote and noisy locations both indoors and outdoors	❑ Improve communication of warnings using computer-assisted script writing, QC, transmission, and notification	❑ Computer-aided warning writing with standardized scripts, e.g., forecaster selects/enters only data that changes, e.g., location, start and stop times ❑ Automated Q.C. to avoid mistakes plus manual approval check by forecaster ❑ Automated transmission by computer over landlines and/or radio, depending on notification/display technology at each site ❑ Multiple diverse notifications depending on number of people affected and operational importance of site and warning ❑ Aural notification: combinations of computer voice generated PA, cell phone, etc. ❑ Visual notification and display: computer-activated status lights, text boards, TV monitors, pagers, fax, etc. ❑ Dial-up tape loop: worker calls phone number to receive computer-controlled/ generated message with all current warnings

Far-Term Objectives for Forecasting Weather			
Objectives	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Provide automated analysis tools to help analyze multiple criteria and calculate quantitative risk assessments for decision makers	❑ Processing and assessing/visualizing increasingly larger and more complex data sets ❑ Data quantity, diversity, and complexity	❑ Improve data assimilation, integration, analysis, and visual fusion tools ❑ Better use of automation and graphical user interfaces ❑ Data fusion approach to analysis tools and decision support capabilities ❑ Visual analysis tools for more rapid analysis and tailored mission products for ease of understanding by decision makers	❑ Improved data assimilation, analysis, and visualization tools, which better display and integrate both weather sensor data and model output, as data complexity increases, spatial and temporal resolution improves, data latency decreases, etc. ❑ Computers fast enough to run above models and tools so output is useful for operational decisions

The ability to provide safe ground and flight tests, ground processing, flight operations, and vehicle deorbit and recoveries depends critically on the Ranges' ability to accurately predict adverse weather; to provide accurate, timely weather warnings; and the ability to both precisely specify weather phenomena and thresholds that endanger safety or mission success, and measure and predict those phenomena and thresholds to reduce the level of uncertainty, reducing diverts, scrubs, and delays. NASA and DoD should support fixed sensor networks that improve the measurements of local and space-based soil moisture; river and ocean temperatures; as well as improvements to remote sensing from radiometers, LIDARs, profilers, GPS, etc. to provide high-resolution four-dimensional measurements of thermodynamic (temperature, moisture, pressure), wind, lightning, and solar/space data. Additional resources should be applied to developing blended system models that weight numerical models, extrapolation techniques, and physics-based rules and can be modified and perturbed by forecasters. The models themselves must have improved spatial resolution and forecast length.

Forecasters and decision makers would also benefit from improved data assimilation, integration, analysis, and visual fusion tools to take full advantage of increased data complexity and spatial and temporal resolution, decreased data latency, etc. Since improved forecasts/warnings are only as useful as the forecaster's ability to quickly and accurately communicate it to decision makers, a key improvement would be automated weather data communication through a variety of methods and displays.

Proposed Development Steps for Forecasting Weather

- **Build Upon the Warning Decision Support System—Integrated Information (WDSS-II)**. The WDSS-II, developed jointly by the National Severe Storms Laboratory and the Cooperative Institute of Mesoscale Meteorological Studies at the University of Oklahoma, is a suite of algorithms and displays for severe weather analysis, warnings, and forecasting. It provides easy access to data from many different sources and provides automated analysis of weather events in real-time.
- **Pursue Synergy With Existing Blended Systems**. The value of several such systems, including the National Center for Atmospheric Research's Auto-Nowcaster, was tested side-by-side at the 2000 Olympics Games. The Auto-Nowcaster integrates data from Doppler radar, satellite, rawinsondes, profilers, surface stations, lightning networks, and numerical weather prediction models. Forecast parameters are derived from these data sets using research results from numerous field programs and numerical modeling simulations. Using fuzzy logic concepts the forecast parameters are converted to values representing likelihood of precipitation and then combined for the final forecast.

Additional Areas for Focused Development

Other Technologies for Forecasting Weather
• LIDARs/hypersodars for high-resolution slant path wind and turbulence just before landing
• Improved remote and in situ measurements of cloud physics parameters
• Field mill and other sensors on UAVs
• Geostationary Imaging Fourier Transform Spectrometer
• Global Environmental MEMS Sensors (GEMS)
• Improved spatial and temporal resolution of atmospheric measurements. Goals for the Global, Mesoscale, and Convective numerical models:

Model		**Global**	**Meso**	**Nowcast**	**Convective**
Spatial (km)	*Now*	50-100	10-20	1-5	1-5.0
	Future	10	1	<1	0.5-1.0
Forecast Length (Hrs)	*Now*	240-720	6-84	1-6	0.5-2.0
	Future	>720	6-120	<1-6	0.5-3.0

- To increase weather product usefulness for operational decisions as data complexity increases, spatial and temporal resolution improves and data latency decreases: (1) computers powerful enough to run above models at increasingly higher, convective-scale resolution and with shorter run times; and (2) improved data assimilation, analysis, and visualization tools.

- Mesoscale Coupled Sea, Land, and Air Model (McSLAM) – a very high-resolution local model with the following features:
  - Integrated estuarine and ocean model for the bottom boundary condition over water
  - Integrated land surface model, including vegetation for the bottom boundary condition over land
  - Incorporation of real-time NEXRAD Doppler velocities for wind field initialization and nudging
  - Incorporation of weather radar reflectivities for convective initialization and nudging
  - Incorporation of near real-time satellite profiles of temperature and water vapor for thermodynamic initialization and nudging
  - Grid resolution of 100 meters or finer with explicit cloud physics
  - Incorporation of all local data from range Mesonet, including wind profilers, weather towers, soil moisture sensors, rain gauges, ACARS, etc., for initialization and nudging.

- Increase accuracy and temporal and spatial resolution of weather Advisories and Warnings (especially lightning and downburst predictions and lightning launch commit criteria evaluation): Improved dual polarmetric radar algorithms, multistatic radar algorithm retrievals, and radiometer algorithms

- Reentry. Improved technology to measure and forecast the Mesosphere (also known as the Ignorosphere): (1). Improve surface and satellite-based and direct measurement sensors to improve understanding of temporal and spatial variability of Mesosphere temperature, density, pressure, wind speed, and direction; and of noctilucent clouds. (2). Ground-based network of mesospheric LIDARs. (3) Global Satellite Observations of upper atmosphere winds (for instance with Spaceborne LIDAR system).

- Techniques/sensors to observe and measure parameters associated with upward lightning strokes, such as their location and energy, and then predict them

- Remotely measure electric fields in clouds
- Recovery - winds along descent flight path: Doppler scanning LIDAR that is reliable, eye safe, affordable
- Modify weather to eliminate or reduce hazards

Launch Commit Criteria Evaluation

The next subfunction in advancing weather support to launch and test ranges is improving the design, threshold values, and evaluation of launch commit criteria. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to safely improve launch availability.

Far-Term Objectives for Launch Commit Criteria Evaluation			
Objectives	**Technical Challenges**	**Technical Approaches**	**Technology Under Development**
❑ Reduce Unnecessary Scrubs & Delays to < 15% due to Lightning LCC	❑ Difficult to infer electric fields along flight paths from measurable meteorological conditions ❑ Rapid spatial and temporal variations in electric fields.	❑ R&D to better understand relationship of electric charge/field along flight path to measurable meteorological conditions ❑ Develop techniques to assess threat of electric charge aloft from routinely available meteorological measurements such as radars and radiometers	❑ ABFM 2 Data Analysis: Analyze data from 2000-2002 Airborne Field Mill (ABFM) missions and revise current lightning launch commit criteria (LLCC) ❑ Physical and statistical model of electric field decay and spatial and temporal variation ❑ Improve cloud property measurements: reflectivity, particle-size distribution, ice vs water, optical depth, etc.
	❑ Each vehicle 'amplifies' electric field differently depending on vehicle length, fuel, plume, etc.; however, currently all vehicles are treated the same	❑ Write lightning LCC specific to individual vehicles ❑ Reduce vehicle vulnerability to lightning	❑ Understanding of electric field thresholds for triggered lightning as a function of each vehicle's characteristics
	❑ Cost effectively measure electric field along flight path just before T-0 with aircraft	❑ Reduce expenses to O&M/calibrate aircraft systems with field mills ❑ Use data from R&D programs above to develop concept of operations ❑ Equip DOL aircraft with wider array of meteorological sensors	❑ Launch day use of ABFM aircraft to accurately measure electric field along flight path just before T-0 ❑ Better understanding of spatial and temporal variations of electric charge to permit refinement of a concept of operations for DOL ABFM aircraft
	❑ Better assimilation, analysis, modeling, and product generation capabilities for assessing impacts and providing appropriate warnings and information	❑ Data fusion and visual analysis tools to more rapidly analyze and tailor mission-specific products for easier understanding by decision makers	
	❑ **Remotely** measure electric field aloft	❑ No technologies identified at this time	❑ May not be possible
Reduce Unnecessary Scrubs and Delays due to Upper Level Winds to < 5%	❑ Balloons have large spatial/temporal errors ❑ Measure upper winds: along flight path with X meters vertical resolution; reduced spatial and temporal variation; better processing/QC algorithms	❑ Use profilers instead of balloons to measure upper winds ❑ Improved data processing and quality control algorithms to include those for multistatic wind profiler radars ❑ Determine each launch vehicle's *realistic* requirements for vertical resolution of ascent winds	❑ Multistatic wind profiler antennae ❑ Dual/tri- Doppler radars to measure winds to required altitude ❑ LIDARs: reliable, eye safe, affordable, and with sufficient power to operate in most weather conditions ❑ Higher resolution profilers and LIDARs - Note: Beneficial only if launch vehicle managers acknowledge the short lifetimes of high-frequency wind features by faster loading of steering commands
	❑ Vehicles require 30 to 120+ minutes to calculate and load steering commands	❑ Update steering commands at L-5 Minutes ❑ Improve Profiler/LIDAR vertical resolution to take advantage of L-5	❑ Better concepts of operations under study ❑ Supplement profilers with LIDAR sensors

Far-Term Objectives for Launch Commit Criteria Evaluation			
Objectives	**Technical Challenges**	**Technical Approaches**	**Technology Under Development**
	after wind data is processed. Delay introduces larger possible errors between measured vs actual ascent winds	steering update	
	❑ Profiler antenna size to measure upper winds is too large for vehicle or satellite	❑ Combine assessment of realistic vertical resolution requirements, with ability to update steering commands much closer to L-0, and improved technology, to reduce profiler size and weight requirements	❑ Same as above

The weather community's ability to more accurately identify and measure the atmospheric phenomena that endanger launch safety and mission success will help reduce the number of scrubs or delays and save the Ranges and customers millions of dollars in wasted resources and lost revenues. To reduce the impact of lightning launch commit criteria (LLCC), research should focus on (1) the relationship of electric fields to meteorological parameters that are measurable in real time during a launch countdown; (2) best methods to directly or (better yet) remotely measure the electric field just prior to vehicle launch; and (3) impact each different vehicle has on the electric field, to allow design of specific LCC for each vehicle. Additionally, DoD, NASA, and launch vehicle manufacturers should continue development of lightning hardened vehicles, flight termination systems, and payloads. Other Range weather technologies requiring improvement are the measurement, processing, and application of upper-level winds. Ranges currently measure upper winds by tracking weather balloons as they are carried by the wind after release. The resulting data resolution is degraded both temporally and spatially - the balloon requires an hour to reach altitude and is normally carried by the wind away from the launch vehicle's flight path. Wind profiler and LIDAR technology allow near-real-time measurements near the flight path - their ability to reliably support real-time operations should be improved, including enhancing their processing and quality control algorithms. However, before these improvements can be fully exploited, vehicle manufactures must determine each launch vehicle's realistic requirements for vertical resolution of ascent winds. Current specifications unrealistically require measurements/resolution of wind features that have lifetimes of less than 20 minutes.

Example technologies under development that could improve decision makers' access to more reliable data include:

Proposed Development Steps for Launch Commit Criteria Evaluation

- **Leverage data from Airborne Field Mill (ABFM) program 2 data.** This research, sponsored by NASA/KSC and the Air Force, was designed to provide scientists data allowing them to recommend more flexible lightning criteria for launch, while keeping the assets as safe or safer than they are now. The better the physics behind lightning is understood, the more precisely meteorologists can determine which weather conditions are unsafe for launch and landing. Data was gathered by flying aircraft that measured electric fields, called field mills, into anvil and other potentially electrified clouds around NASA/KSC and Cape Canaveral Air Force Station (CCAFS). Lightning launch commit criteria have already been modified as a result of this research. A new data gathering and analysis program including radiometers and multipolarization radar should be developed to improve the process even more.

- **Use wind profilers instead of balloons to measure upper-level winds**. Whether ground-based, space-based, or flight vehicle-based, wind profilers, which are operated at many places around the U.S. and around the world, can produce real-time measurements of winds aloft at or near the location where the launch vehicle will fly and with much greater frequency. A radar wind profiler is a specialized Doppler radar that produces a wind measurement above the radar. The more accurate and timely measurements provide decision-makers more realistic and relevant data near the flight path, thus allowing quicker identification of changes in the upper winds. This cannot only better ensure vehicle safety but also reduce the need for conservative wind margins and thus allow more operations to proceed when weather actually does permit.

Additional Areas for Focused Development

Other Technologies for Forecasting Weather
• Based on results of ABFM-2, initiate new ABFM-3 Data Gathering and Analysis Program to include radiometers and multipolarization radar
• Physical and Statistical model of Electric Field Generation
• Improve remote measurements of cloud reflectivity, particle size distribution, ice vs water, optical depth, etc.
• Lightning hardened vehicles, FTSs, and payloads
• Ability to remotely measure the electric field along and upstream of the flight path (may not be feasible)
• Day of launch aircraft equipped with field mills, plus other instrumentation such as 1-3 centimeter radar, dropsondes, cloud sensors, and the ability to download data to the ground in real time (helps evaluate possible spatial and temporal variations in electric field near flight path)
• Procure and develop a concept of operations for multistatic radars and LIDARs
• Higher resolution profilers and LIDARs. Beneficial only if launch vehicle managers acknowledge the short lifetimes of high-frequency wind features by faster loading of steering commands
• LIDAR sensors to measure upper-level winds that are reliable, eye-safe, and affordable
• Vehicle-based wind profilers (possible?)
• Satellite-based wind profilers (possible?)

Toxic Corridor, Radiation Concentrations, Debris Impact Points, and Blast Predictions

A third subfunction in weather support to launch and test ranges is improving the accuracy and resolution of meteorological data required by Range Safety to predict toxic corridors, radiation concentrations, debris impact points, and blast (acoustic) impacts. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address toxic, radiation, debris, and blast predictions.

Far-Term Objectives for Toxic Corridor, Radiation Concentrations, Debris Impact Points, and Blast Predictions

Objectives	Technical Challenges	Technical Approaches	Current Technology Under Development
Improve Forecasts of: 1. Toxic Corridors ❑ Resolution: 0.5km ❑ Toxic Concentration Accuracy: 99% 2. Radiation Fallout ❑ Resolution: 0.5km ❑ Concentration Accuracy: 99% 3. Debris Fallout ❑ Resolution: 0.5 km ❑ Debris Fallout Accuracy: 99% 4. BLAST Casualties ❑ Accuracy: 99% ❑ Resolution: 0.5 km	❑ Improve measured and forecast vertical and horizontal structure of boundary layer wind, turbulence, temperature and moisture fields; and data assimilation ❑ Quantity and quality of data available to feed numerical weather models ❑ Data with sufficient vertical and horizontal resolution	❑ Increase environmental inputs to mesoscale weather models: especially soil moisture, turbulence, sea, and river temperatures, etc. ❑ Improve boundary layer wind and temperature structure measurements ❑ Improve temporal and spatial resolution of data feeding models ❑ Improve Mesoscale models: physics assumptions; speed; 4D resolution; accuracy	❑ ***Refer to Discussions of Data and Models under Spaceport Operations*** ❑ Buoy sensors: Profilers for wind, temperature, and moisture; field mills ❑ Improved remote sensing and understanding of cloud microphysics ❑ River sensors - salinity, temperature vs. water depth ❑ Soil moisture sensor networks using: 1. radar from towers; 2. GPS ❑ GPS-based total precipitable water sensors ❑ Transition MM5 to replace RAMS as mesoscale model for Eastern Range Dispersion Assessment System (aka MARSS)
	❑ Remote measurements of toxic and radiation concentrations	❑ Measure Gas and Aerosol Concentration	❑ Remote sensors: eye safe, tunable scanning doppler LIDAR
	❑ Improve physical models of vehicle breakup, population density, and impacts of acoustics on windows and thus casualties	❑ Considerable data gathering and analysis required to develop models	
	❑ Modify toxics, radiation, debris, and blast models to be embedded within 4D numerical forecast model	❑ Improve debris and BLAST models to automatically ingest numerical model forecast atmospheric parameters	❑ Transition to 3D multipuff dispersion models, e.g., range dispersion 3D model (RD3D)
	❑ Better analysis, modeling, and product generation capabilities for assessing impacts and providing appropriate warnings and information ❑ Data assimilation, integration, and analysis of numerous, rapidly changing parameters	❑ Data fusion approach to analysis tools and decision support capabilities ❑ Platform system integration for remote sensing and physical sampling sensors, command and control, and meteorological and safety physics analyses ❑ Visual analysis tools for more rapid analysis and tailored mission-specific products for ease of understanding by decision makers	❑ Data assimilation, integration, analysis, and visual fusion tools ❑ Portable PDA for 24/7 emergency calculations ❑ Mission Accredible Radio Connected Intranet (MARCONI)

Measuring and predicting surface and boundary layer winds and temperature structure are important for ensuring the safety of otherwise hazardous ground processing, launch, and recovery operations. The ability to predict toxic corridors, debris impact points, radiation concentrations, and blast impacts would be enhanced by the same technology development requirements, discussed earlier for improving forecasts for space operations and recovery. This includes improving the models' spatial and temporal resolution of measured and forecast thermodynamic and wind data, especially in the boundary layer, and capabilities to automatically ingest numerical atmospheric model outputs. Improved models and visual fusion tools will improve decision makers' ability to assess impacts and provide accurate, timely warnings and information.

Proposed Development Steps for Toxic Corridor, Radiation Concentrations, Debris Impact Points, and Blast Predictions
• **Leverage recent upgrades to Eastern Range Dispersion Assessment System (ERDAS)**. Currently, the Eastern Range Meteorological and Range Safety Support/Eastern Range Dispersion Assessment System (ER MARSS/ERDAS) is undergoing upgrade to add new toxic and blast hazard prediction models, integrate new local area weather with higher resolution, and upgrade graphical and map display components. These improvements will provide meteorologists and safety engineers with better chemical hazard predictions and continuous hazard modeling.

Additional Areas for Focused Development

Other Technologies for Toxic Corridor, Radiation Concentrations, Debris Impact Points, and Blast Predictions
• Mesoscale models with spatial resolution <1kM; forecast length: 1-96 hours; coverage: nested—regional-local; and run time: <1/10 forecast length
• Mesoscale coupled sea, land, and air model
• Acquire measured turbulence values from 915 MHZ profilers and mini-sodars
• Improve resolution and frequency of 3-D wind and temperature measurements
• Acquire measurements of soil moisture and sea surface/river temperature
• Remotely measure location and toxic concentration in abort clouds for input to improved dispersion models
• Improved climatology of short-term variance of atmospheric properties for use in risk models
• Update vehicle breakup characterization and debris categories
• Spectral Comparative Imagery

• Differential Absorption LIDAR and Radar
• Migrate to higher resolution, more accurate Mesoscale prediction and Toxic Dispersion, Radiation, Blast, and Debris models
• Embed Toxic, Debris, Blast, and Radiation within a 4D numerical weather model with rapid update cycles
• Improved climatology of short-term variance of atmospheric properties for use in risk models
• Improved high-resolution numerical models to support multiple launch and recovery sites
• Use of artificial intelligence to identify specific real-time meteorological data deficiencies necessary to resolve marginal go/no go decisions.
• Improved analysis and visualization tools as data complexity increases, spatial and temporal resolution improves, data latency decreases, etc.

Space Forecasts

Another important subfunction in weather support to launch and test ranges is improving space forecasts. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to improve space forecasts.

Far-Term Objectives for Space Forecasts

Objectives	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ Reduce delays and scrubs and impacts on spacecraft due to uncertainties in solar activity, solar wind, interplanetary medium, electromagnetic radiation, particle radiation, ionospheric activity, geomagnetic activity, etc. ❑ Forecast all the above phenomena	❑ Lack of Data to (1). sufficiently understand Solar, magnetospheric, and ionospheric physical processes;(2). develop models; and (3).input into models	❑ Improve observations and forecasts of proton, electron, and x-ray flux and the magnetosphere	❑ Improved solar and ionospheric data and forecast models ❑ TBD
❑ Develop better understanding of mesosphere (100-400 km) and mesospheric phenomena such as noctilucent clouds	❑ Insufficient data gathered in upper atmosphere including mesosphere ❑ *See details in Recovery section*	❑ Determine and implement more routine data gathering and archiving of mesosphere data ❑ *See details in Recovery section*	*See details in Recovery section*
❑ Develop Space Weather Alert System to warn of impending communication and navigation failures, high-radiation levels, etc.	❑ Ability to quickly view numerous parameters in 4D (x,y,z ,t) ❑ Improve data assimilation, integration, analysis, and visual fusion tools	❑ Data fusion approach to analysis tools and decision support capabilities ❑ Improve data assimilation and visualization tools for more rapid analyses, and tailored mission specific products for ease of understanding by decision makers	❑ Data assimilation, integration, analysis, and visual fusion tools

Proposed Development Steps

The DoD and NASA weather communities should continue to improve the sources and methods of collecting data needed to forecast space conditions. Models that allow meteorologists to understand solar, magnetospheric, and ionospheric physical processes and activity should be developed, as well as tools that improve data-gathering techniques and capabilities.

Proposed Development Steps for Space Forecasts

- **Adapt data assimilation and visual fusion tools**. Technological developments are improving operations in other areas addressed in this paper. As the resolution, accuracy and data refresh rate increase, industry must increasingly develop improved capabilities to display data meaningful to both meteorologists and to decision makers.

Additional Areas for Focused Development

Other Technologies for Space Forecasts
• Improved technologies to allow accurate monitoring and forecasting of mesosphere temperature, density, pressure, wind speed, and wind direction worldwide.
• New capabilities to better measure and forecast proton, electron, and x-ray flux and magnetosphere and ionosphere behavior
• Develop space weather alert system to warn of impending communication and navigation failures or high-radiation levels.

People and Infrastructure

The last subfunction in weather support to launch and test Ranges is making good use of personnel and modernizing the weather infrastructure. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development.

Far-Term Objectives for People and Infrastructure Associated with Weather Measurement and Forecasting

Objectives	Technical Challenges	Technical Approaches	Current Technology Under Development
❑ Requirements for forecaster intervention/labor hours reduced: 90%	❑ Occasional errors in data input into forecast models ❑ Forecast model errors	❑ Improve data input quality control algorithms ❑ Improve numerical models in order to reduce requirements for forecaster intervention/labor hours: 35% (2007), 70% (2012), and 90% (2020) ❑ Data fusion approach to analysis tools and decision support capabilities ❑ Visual analysis tools for more rapid analysis and tailored mission-specific products easily understood by decision makers	❑ Improved automated forecasts and decision assistance algorithms
❑ Forecast Hubs for 80% of Space Program	❑ Sufficiently flexible and accurate forecast and communications technology to allow tailored forecasts for specialized operations at each Spaceport ❑ Bureaucracy associated with a forecast hub supporting Spaceports managed by diverse State, Federal, and commercial organizations	❑ Centralize forecast support in hubs supporting multiple Ranges and Spaceports	❑ Technologies discussed under *Spaceport Operations and Recovery*; for instance, very accurate forecast models with higher spatial and temporal resolution:
❑ Reduce number of local weather sensors at each Spaceport needed to gather and communicate the high-resolution wind and thermodynamic required to feed local Spaceport & Range Mesoscale models	❑ Communications: Sufficient space to ground bandwidth ❑ Air/Space-based sensors with sufficient resolution	❑ Replace ground-based sensors with space-based sensors - must have the spatial and temporal resolution and accuracy to satisfy local mesoscale model data requirements ❑ Improve power available aboard satellites and their bandwidth to Earth	❑ Space-based sensors able to replace local ground-based sensors and service multiple Ranges/Spaceports with data to feed forecast models
❑ Technology Transition Units servicing all US Spaceports/Ranges ❑ Advanced degree meteorologists assisting all nodes developing or modifying space systems or designing operations concepts	❑ Recognition of the importance of technology transition to address the Space Program's unique atmospheric requirements ❑ Air Force reducing number of Advance Degree Meteorologists ❑ Air Force considering outsourcing of Eastern and Western Range weather support	❑ Colocate Technology Transition Unit with weather operations as much as possible ❑ Assign advance degree meteorologists to space system development SPOs and to Spaceports/Ranges	❑ Technology Transition Unit currently located with Range Weather Operations at Cape Canaveral Spaceport ❑ Outsourcing 45th and 30th Weather Squadron would be detrimental to the Space Program

The DoD and NASA weather communities should continue to concentrate efforts on improving the education and infrastructure tools of their most valuable asset: the skilled meteorologists that provide decision makers information key to operational success. An innovative concept that illustrates the advantage of the synergies provided by pooling Atmospheric Scientists with knowledge of the space community's unique atmospheric requirements is the Applied Meteorology Unit (AMU), which has been colocated with Range Weather Operations at Cape Canaveral Air Force Station since 1991. The AMU helps agencies meet new or existing requirements by evaluating and developing new technologies. If a technology is viable, the AMU transitions the technology into operations.

Other technologies and concepts under development that will improve value of weather people and infrastructure include:

Proposed Development Steps for People and Infrastructure Associated With Weather Measurement and Forecasting

- **Higher resolution computer forecast models.** Models capable of better forecasting the time and location of occurrence of weather phenomena hazardous to ground operations, launch, flight and recovery, can, in combination with the capability described immediately below, allow centralization of weather support in hubs.
- **Improve weather forecasting systems to reduce the requirement for forecaster intervention**. Improved automated forecast and decision assistance algorithms require development of systems that will automatically sense, quality control, analyze, display, and archive data and transform that data into forecasts and warnings. The time saved will allow forecasters to tailor forecasts to meet the precise, unique requirements of weather-sensitive operations, thus increasing safety, productivity, and mission success.

Additional Areas for Focused Development

Other Technologies for Space Program Forecasts
• Significantly increased communications downlink bandwidth and power aboard satellites with atmospheric sensors
• Use advanced degree meteorologists in the design of vehicles and payloads and the development of concepts of operations. The Air Force should assign meteorologists with experience and advanced degrees to the Space and Missile Center to ensure the impact of the atmosphere is fully assessed during the design of new space systems and the concepts of operations for ground processing, launch, flight, reentry and recovery. This could save millions of dollars during subsequent testing, development, and operations.
• Accelerate development of space sensors serving multiple Spaceports and Ranges to replace local sensor networks
• Centralized Spaceport/Range Forecast Hubs and Technology Transition Hubs supporting multiple spaceports and ranges. (Requires the improved models and displays discussed in Spaceport Operations and Recovery.)

Weather Measurement and Forecasting Technology Roadmap

The following technology roadmap (see Figure 31) displays the major technology areas, with time-phased recommendations regarding particular technologies to pursue in improving the ability of launch and test ranges to conduct weather measurement and forecasting activities.

Key technologies for weather measurement and forecasting include better meteorological sensors, models, and data fusion to improve forecasts for spaceport operations and improved communications to relay important weather information; more flexible yet safer lightning and upper-level wind launch commit criteria; improved modeling that enhances toxic corridor, radiation concentration, debris fallout, and blast predictions; better use of tools and meteorologist expertise to develop safer launch vehicles; and models that allow meteorologists to better understand the mesosphere and space and predict the impact on launch vehicles.

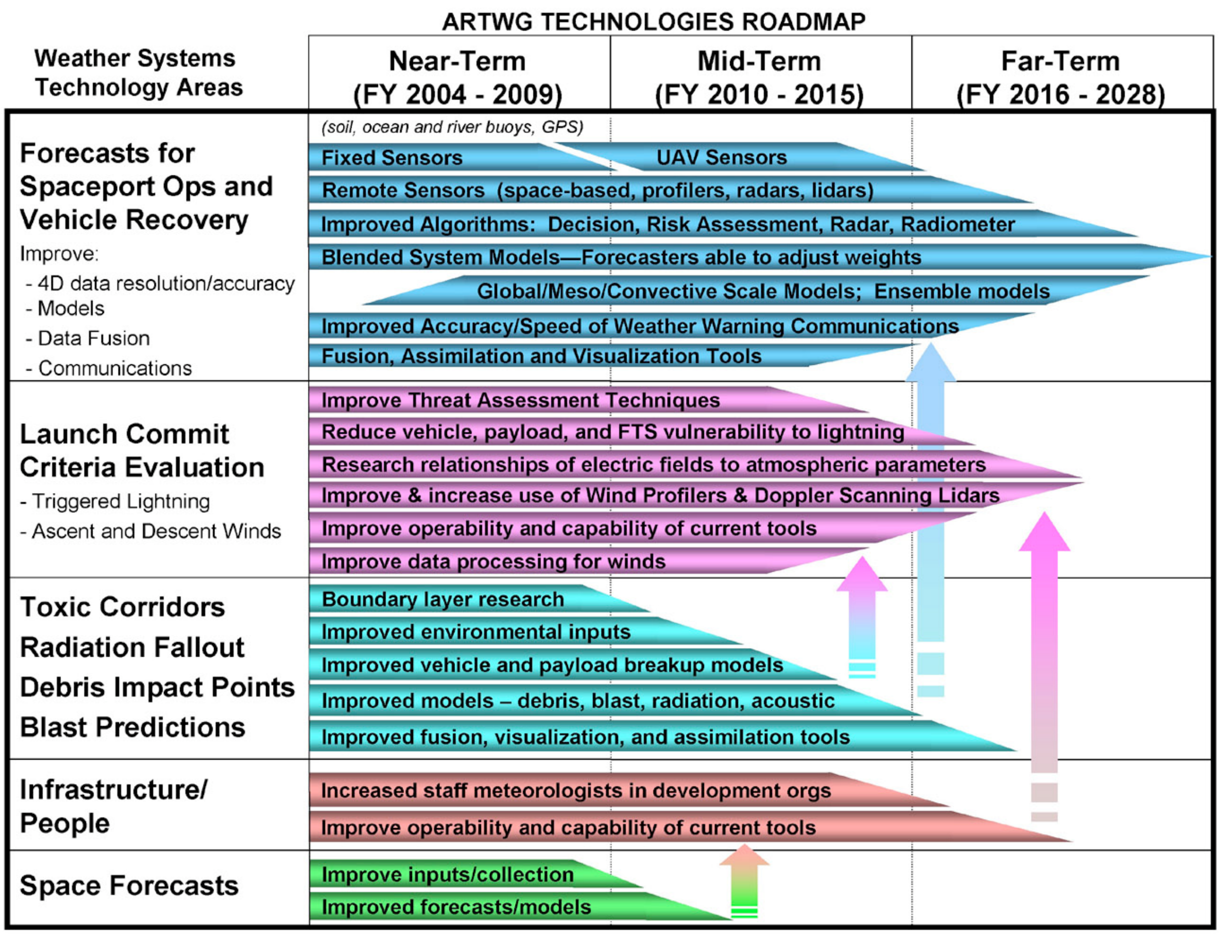

Figure 31 Technology Roadmap for Weather Measurement and Forecasting

CROSS-CUTTING ARCHITECTURE AND PERFORMANCE MEASURES

CROSS-CUTTING ARCHITECTURE AND PERFORMANCE MEASURES

The following top-level capability roadmap (see figure 32) lists the qualitative goals for improved range cross-cutting architecture performance over time, as previously summarized with the other range functions.

ARTWG envisions cross-cutting capabilities evolving over time to result in commonality among the various subgroups, self-healing networks enhancing the delivery of services within the subgroups, autonomous control and interactive simulation and testing for all operators.

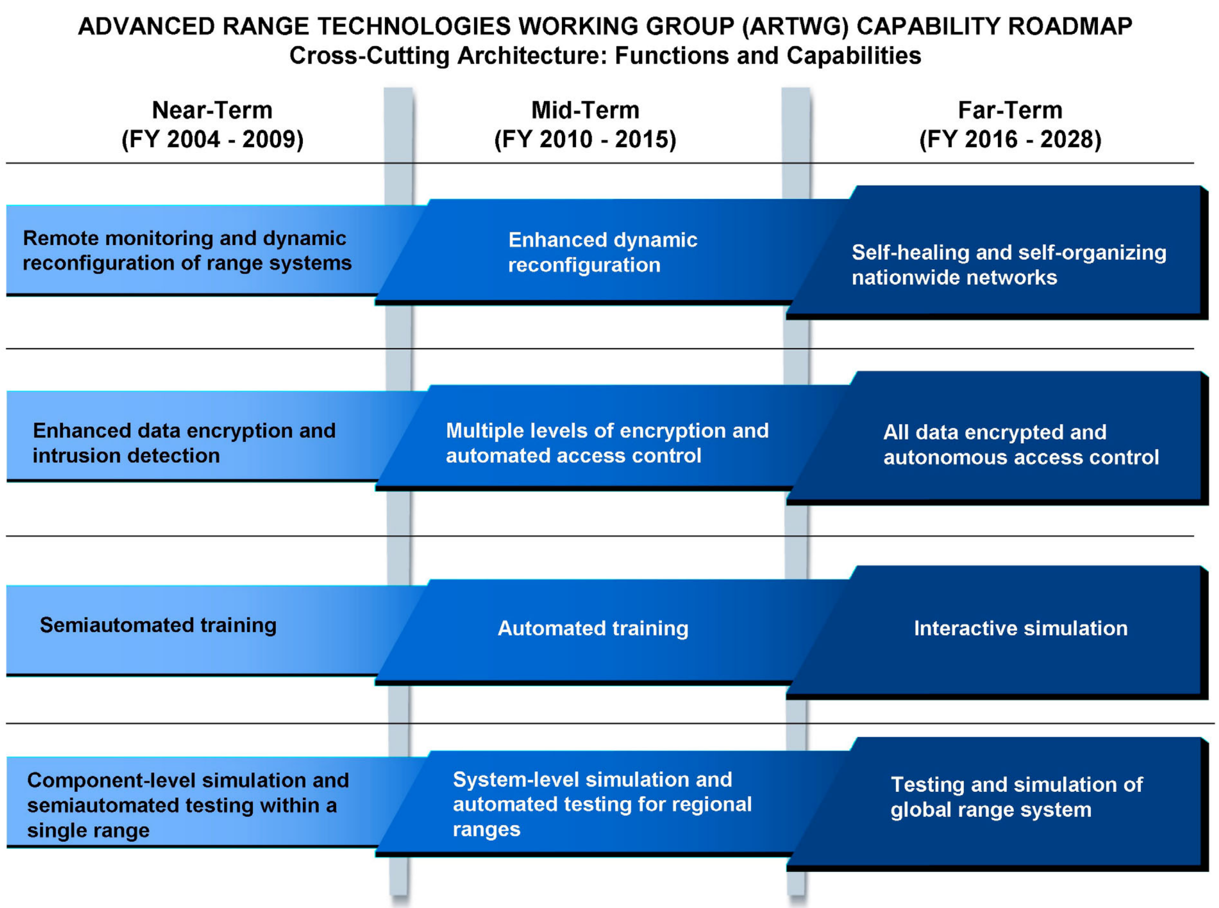

Figure 32 Capability Goals Over Time: Cross-Cutting Architecture

The following subfunctions and capability goals (see Figure 33) were identified by the subgroups as elements of the range cross-cutting architecture function:

Subfunctions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Long-Term (FY 2016 - 2028)
Integrated Health Management	❑ Simple network management protocol (SNMP) ❑ Remote monitoring (embedded message as an approach) ❑ Dynamic reconfiguration	❑ Enhanced dynamic reconfiguration	❑ Self-healing networks ❑ Tie into national networks ❑ Virtual presence
Security and Resource Protection	❑ Reduce the amount of red/black systems ❑ Enhance network intrusion detection and response ❑ Enhance data encryption ❑ Strong authentication of users ❑ Limited physical security control ❑ Protect proprietary information	❑ Multiple levels of data encryption to align with classification levels ❑ Automated access control	❑ All data encrypted and protected ❑ Autonomous access control
Simulation and Testing of Range Assets	❑ Batch-mode simulations based on previously defined requirements ❑ Limited support for measurement manipulation ❑ Limited modeling of components ❑ Semiautomated testing to include virtual testing ❑ Provide a limited testing and simulation capability ❑ Provide a modeling and simulation capability for a single range	❑ Modeling of entire environment and systems ❑ Automated testing to include virtual testing	❑ Provide a robust, global testing and simulation capability
Use of Simulation for Training of People	❑ Semiautomated training ❑ Simulate before use ❑ Real-time ❑ Provide a limited training and simulation capability ❑ Provide a training and simulation capability for a single range	❑ Virtual distributed testbed ❑ Provide automated training	❑ Virtual simulation ❑ Interactive simulation (manipulate data) ❑ Interconnected across systems ❑ Available across national range community ❑ Multiple pieces of the space transportation system ❑ Scalable/modular simulations ❑ Addresses both outgoing and incoming flights ❑ Provide a robust, global training and simulation capability

Figure 33 Cross-Cutting Architecture Functions and Capability Goals Over Time

Cross-Cutting Performance Measures

The following top-level capability roadmap (see Figure 34) lists the qualitative goals for improved range cross-cutting architecture performance over time, as previously summarized with the other range functions.

ARTWG envisions cross-cutting performance measures evolving over time to result in commonality among the various subgroups, self-healing networks enhancing delivery of services, autonomous control, and interactive simulation and testing for all operators.

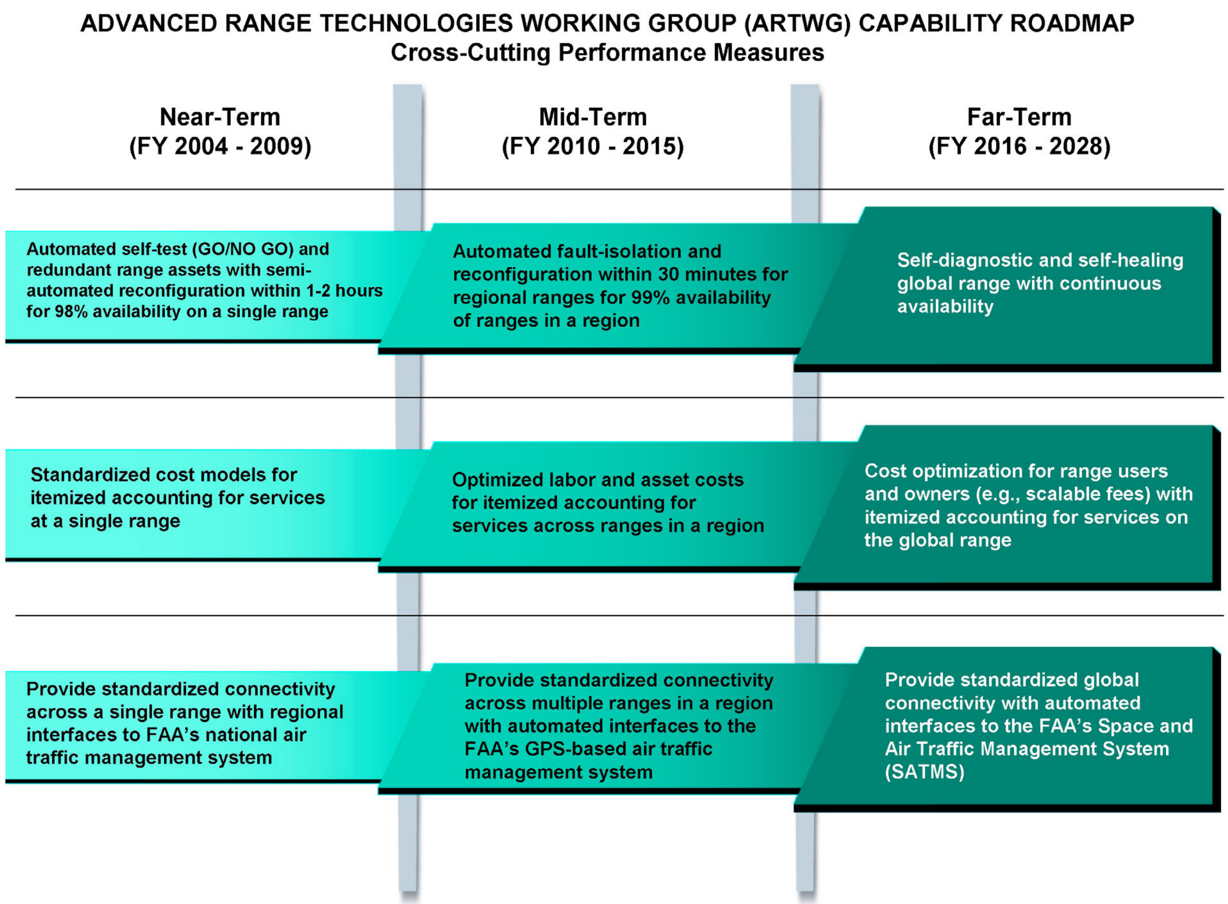

Figure 34 Capability Goals Over Time: Cross-Cutting Architecture Roadmap

Figure 35 further addresses cross-cutting performance measures over time:

Subfunctions	Near-Term (FY 2004 - 2009)	Mid-Term (FY 2010 - 2015)	Long-Term (FY 2016 - 2028)
Availability	❑ Limited user availability as needed ❑ Remotely turned on for the local system on user demand ❑ 98%	❑ Available as needed ❑ 99%	❑ Continuous availability (100%) ❑ Available on demand ❑ Open up to the global network
Reconfiguration Time	❑ Semiautomated systems reconfiguration ❑ Reconfigure from one operation to another in 1-2 hours	❑ Automated systems reconfiguration ❑ Reconfigure from one operation to another in 30 minutes	❑ Autonomous reconfiguration ❑ Full up capability 24/7
Reliability	❑ Add redundant range assets ❑ Automated self-test (go/no-go)	❑ Automate reconfiguration performance while balancing failure-mode and downtime risks ❑ Automated fault isolation	❑ Dynamic, reconfigurable systems ❑ Self-diagnostic and annealing ❑ Self-organizing and self-healing
Cost	❑ Standardize cost models ❑ Itemized accounting for services at a single range	❑ Optimized labor and asset cost ❑ Itemized accounting for services within a region	❑ Cost optimization for the customer and owner (e.g., pay for service/scalable fees) ❑ Itemized accounting for global services
Interoperability across ranges and FAA air traffic management systems	❑ Provide standardized connectivity across a single range ❑ Regional interface with national air traffic control system	❑ Provide standardized connectivity across multiple ranges ❑ Automate interface with FAA's national and regional GPS-based air traffic management systems	❑ Provide standardized global connectivity ❑ Interface with FAA's space and air traffic management system (SATMS)
Maintainability (MTTR, Return to Service time)	❑ 1 hour	❑ minutes	❑ Self-healing in seconds

Figure 35 Cross-Cutting Architecture Performance Measures Over Time

The following tables further address each subfunction by listing a number of quantifiable technical objectives, associated technical challenges, and technical approaches that could be pursued to achieve the performance objectives. The tables also list a number of current projects underway that could enable the development or demonstration of technologies and systems that address the technical challenges. Following the tables is a listing of proposed technologies needs that remain to enable achieving the objectives.

The first subfunctions in cross-cutting is the availability, reconfiguration time, reliability, and maintainability within and across the various subgroups. The following table summarizes the specific objectives, technical challenges, approaches, and current technology projects under development to address the availability, reconfiguration time, reliability, and maintainability for cross cutting.

Far-Term Objectives for Availability, Reconfiguration Time, Reliability, Maintainability			
Subfunctions	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Availability, Reconfiguration Time, Reliability, Maintainability	❑ Communications ❑ Multiple data formats including many analog systems ❑ Large amounts of data ❑ COTS equipment ❑ Affordability (i.e., cost	❑ Mobile, deployable systems ❑ Automate systems ❑ Space-based technology ❑ Central Data Storage and Servers ❑ Web-based browser access to data via Internet	❑ High-altitude airships (HAA) ACTDs by MDA, NORAD, Army, Navy, FAA ❑ Ballistic Missile Range Safety Technology (BMRST) by AFRL, SMC/RSLP and FLANG ❑ UAV development by DoD and NASA ❑ NSF grant research ❑ TOPS demonstrated on STS-87 in 1997 (NASA MSFC project by AZT technology) ❑ Test solutions LLC built-in test equipment ❑ Automotive diagnostic systems

Additional Areas for Focused Development

Other Technologies for Availability, Reconfiguration Time, Reliability, Maintainability
• Technologies to enable self-monitoring, self-healing, self-annealing systems - intelligent fault recovery systems
• Self-repairing/maintaining equipment
• Autonomous, self-learning technologies
• Faster and more efficient algorithms
• Self-organizing networks
• Autonomous, self-learning technologies
• Self-repairing/maintaining equipment
• Automated checkout and recertification

The second subfunction in cross cutting deals with the interoperability across ranges and with FAA. The issue is not one of a lack of standards. The issue is the vast ways to which one can interpret the standards that cause interface/interoperability problems. This leads to a non-material solution in certain aspects. The following table summarizes the specific, objectives, technical challenges, approaches, and current technology projects under development to address the interoperability across ranges and with FAA for cross-cutting.

Far-Term Objectives for Interoperability Across Ranges and With FAA			
Subfunctions	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Interoperability across ranges and with FAA	❑ Data degradation ❑ Environmental controls for storage media ❑ Lack of standardization for media and multiplexing formats	❑ Digitization ❑ COTS ❑ Space-based technology ❑ More robust ground-networks ❑ Different media that does not require strict environmental controls ❑ Storage materials technology	❑ NASA JSC MCC LAN Replacement project ❑ NASA JSC MCC architecture initiative ❑ AFRL/SMC/RSLP mobile range system ❑ FAA Commercial Space Transportation ConOps ❑ FAA Space and Air Traffic Management System (SATMS) ❑ NASA MSFC Ground Systems Dept distributed operations system for ISS ❑ Global Information Grid (AFRL/IF)

Additional Areas for Focused Development

Other Technologies for Interoperability Across Ranges and With FAA
• Defined and common interpretation of standards for display hardware and software
• Common network protocols for data sharing and communications

The third subfunction in cross-cutting deals with security of the various systems within the subgroups. The following table summarizes the specific, objectives, technical challenges, approaches, and current technology projects under development to address security for cross-cutting.

Far-Term Objectives for Security			
Subfunctions	**Technical Challenges**	**Technical Approaches**	**Current Technology Under Development**
❑ Security	❑ Modifications to multiprotocol label switching (MPLS)	❑ Automated systems ❑ Adaptive learned software ❑ Media-independent communication interface	❑ NASA JSC MCC LAN Replacement project, architecture initiative ❑ NASA MSFC Ground Systems Dept distributed operations system for ISS ❑ Dynamic, self-adapting communications (AFRL/IF) ❑ Multi-level security technologies (AFRL/IF) ❑ Software intelligent agents (AFRL/IF) ❑ Data hiding (AFRL/IF)

The third subfunction in cross-cutting deals with cost of the various systems within the subgroups. The following table summarizes the remaining technology approaches/needs or considerations within the subgroups when addressing cost for cross-cutting.

Additional Areas for Focused Development

Other Technologies for Interoperability Across Ranges and With FAA
• Leverage technologies and demo capabilities with funding and uses in other applications besides ranges
• Incremental demo approach, leveraging synergies to reduce costs for certification for use on ranges

Cross-Cutting Architecture Technology Roadmap

The following technology roadmap (see Figure 36) displays the major technology areas, with time-phased recommendations regarding particular technologies to pursue in improving the ability of launch and test ranges to perform various functions across the subgroups.

Key technologies for cross-cutting architecture include automated systems, autonomous self-repairing systems, integrated system health monitoring and self-healing, software intelligent agents, data fusion, model and network-based embedded software for testing.

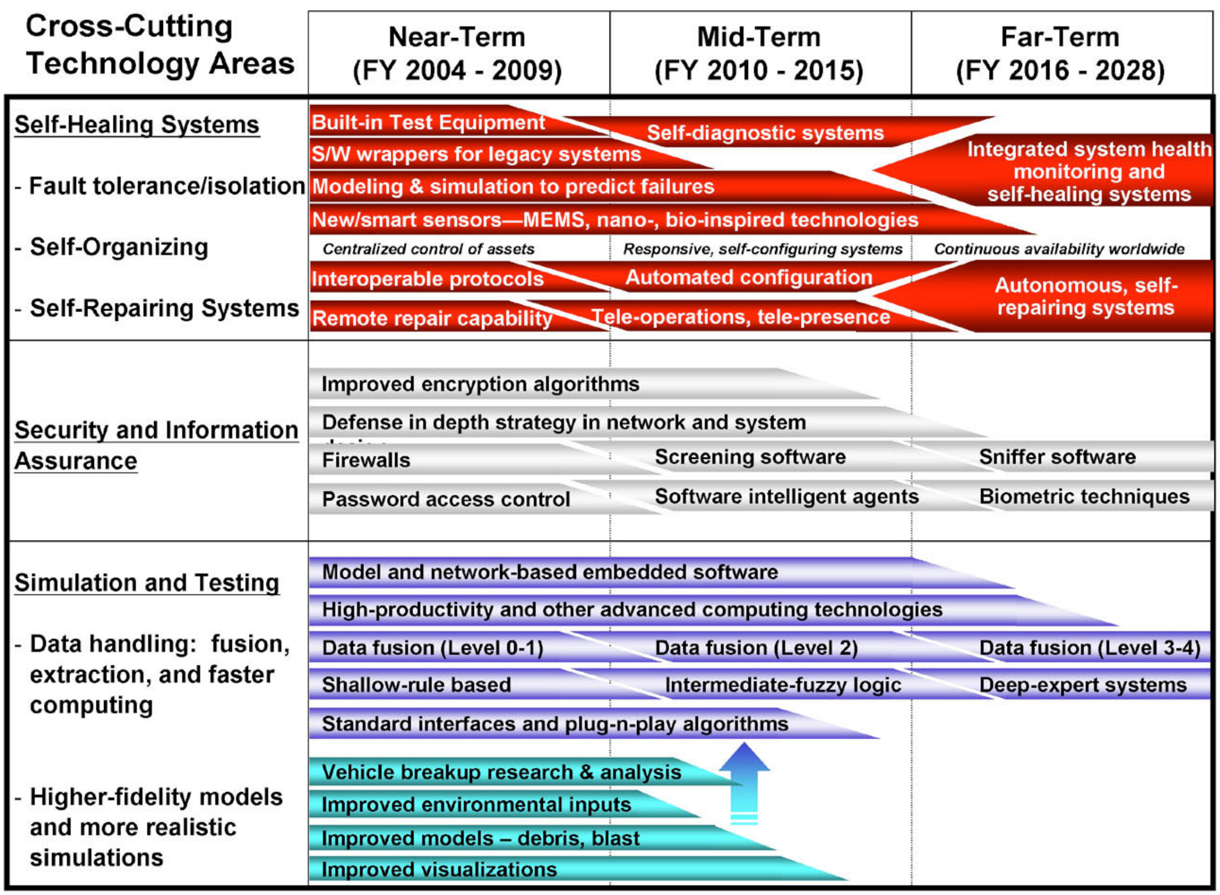

Figure 36 Technology Roadmap for Cross-Cutting Architecture

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CONCLUSION AND RECOMMENDATIONS

CONCLUSION AND RECOMMENDATIONS

Under the shared leadership of the Air Force and NASA, the ARTWG has carried out the recommendation from the February 2000 interagency report on *The Future Management and Use of the U.S. Space Launch Bases and Ranges* to "develop a plan to examine, explore, and proceed with next-generation range technology development and demonstration." The capability and technology roadmaps presented in this report outline the technologies and demonstrations that should be pursued to enable the development of next-generation range capabilities that would "improve safety, increase flexibility and capacity, and lower costs for reusable and expendable launch vehicles" while also enabling support for emerging and projected test and evaluation missions.

The next step along the path toward developing more capable and efficient next-generation space launch and test ranges should focus on how to "proceed with next-generation range technology development and demonstration," as recommended by the interagency report.

- This should begin with a coordinated interagency effort to pursue the resources and authority necessary to orchestrate and conduct the technology development and demonstration activities outlined in the roadmaps.

- A coordinated interagency program involving multiple Government agencies should be created to direct and coordinate the development and implementation of a coherent overall strategy and plan for the nation's development of a primarily space-centric range capability supplemented by mobile range assets.

The most pressing range support issues that must be addressed and resolved in the near-term include:

- Access to and efficient use of frequency spectrum to support range functions and users.

- Target/miss distance measurement to support increasingly complex and diverse ballistic missile defense testing scenarios involving new geographic areas and multiple flight vehicles.

- Data relay issues associated with use of satellites, particularly in GEO, for range and user telemetry, communications, and command and control.

- Operationally responsive range to support rapid range launch and reconfiguration for the Operationally Responsive Spacelift (ORS) Program.

Both within and outside the range community, many opportunities for synergy exist among a variety of ongoing programs, and research, development, and demonstration activities. These activities should be leveraged and pursued to enable the spiral development of new range capabilities that will be useful in incrementally improving the capability and efficiency of the nation's ranges. The ultimate goal of these efforts should remain focused on achieving the vision for a next-generation space launch and test range capability.

The following specific opportunities for synergy should be pursued as part of the overall strategy to pursue the technologies and demonstrations included on the ARTWG technology roadmaps:

- NASA, commercial, and DoD UAV technology and development efforts should be leveraged to assist the range community in affordably developing and demonstrating the use of mobile range assets to provide additional capabilities, capacity, geographic coverage, adaptability, and flexibility in providing range support when and where needed.

- Missile Defense Agency, Army, Navy, Coast Guard, and FAA interest in high-altitude airships for area surveillance should be leveraged and pursued as an area for synergistic development and demonstration, ultimately leading to low-cost, multiple-use mobile platforms for range instrumentation and assets.

- Ballistic missile defense test scenarios and separate flight test activities being pursued under the joint DoD-NASA National Aerospace Initiative (to develop and demonstrate hypersonic propulsion technologies and vehicles) will require a variety of expanded range support capabilities. The range community should pursue synergistic opportunities to demonstrate new space-based and mobile range technologies and capabilities to provide support during these flight test missions.

- The Defense Information Systems Agency (DISA) Joint Interoperability Test Command (JITC) is responsible for "Global Information Systems Testing for the 21st Century" independent operational T&E of DoD Command, Control, Communications, Computers and Intelligence (C4I) systems, identifying and solving C4I interoperability deficiencies, and providing interoperability T&E and certification. JITC's efforts to address efficient, interoperable data links and its expertise in interoperability certification could be leveraged by the range community in its efforts to apply technologies, approaches, and techniques to range C4I systems and capabilities.

- The Joint Advanced Missile Instrumentation (JAMI) program should be viewed by the range community as a significant opportunity for synergistic development of on-board flight vehicle instrumentation to more efficiently interface with range systems, including demonstrations of new technologies and systems. In January 2003, DoD's Central Test and Evaluation Investment Program (CTEIP) Office released a solicitation for the JAMI time space position information (TSPI) unit development (JTU-II) development for applications in Air Force, Army, and Navy small missile tests and training. According to the solicitation, "The program will provide GPS/IMU based TSPI, missile/weapon attitude and vector scoring for range safety and test and evaluation applications, and will also provide a method to track missiles and targets without the relying on ground based radar by utilizing existing telemetry links and infrastructure. The JAMI components include both airborne and ground based systems. The high dynamic TSPI unit is the airborne component of the system. It will provide GPS and IMU data that can be processed on the ground and refined to high accuracy. The high-dynamic TSPI unit is the purpose of this acquisition."

- DoD's Multi-Service Target Control System (MSTCS) Project should be leveraged to develop systems capable of providing precise tracking data for space launch and flight test vehicles as well as target control for vehicles involved in missile defense testing. MSTCS is a modular, interoperable GPS-based TSPI acquisition and Target Control System (TCS) including high- and low-rate data links, which the Army, Navy, and Air Force have options to buy in follow-on procurements. In one follow-on buy in 2002, the Air Armament Center at Eglin AFB awarded Cubic Corporation a $4 million contract to develop 10 prototype Data Link Transceiver (DLT), units using a modified version of Cubic's Tactical Common Data Link (TCDL) technology to provide advanced, two-way data links between multiple targets and ground control stations. TCDL uses commercially available components and is already being used to transfer radar images and data from manned and unmanned aerial vehicles to Navy ships and Army ground stations.

- The UAV Battlelab at Eglin AFB is pursuing significant developments in digital video data compression technology that should be explored and leveraged by the range community as a means of making more efficient use of frequency spectrum on space launch and flight test ranges.

- The Naval Research Laboratory has been pursuing work to develop wide bandgap semiconductor materials and technologies to enable development and use of higher frequency amplifiers. This work should be leveraged by the range community to include construction of prototype hardware to demonstrate use of higher frequencies for telemetry, communications, and command and control in conjunction with other range technology demonstration activities.

- The range community should engage with the Transformational Communication Office to ensure its plans and programs include considerations to accommodate future range systems and requirements. According to the Under Secretary of the Air Force and Director of the National Reconnaissance Office, Mr. Teets, the Transformational Communication System is intended "to assure that we have communications compatibility across the Department of Defense, the intelligence community and NASA." It is also intended to remove bandwidth constraints through a new network of high-capacity satellites for use in combination with the Global Information Grid.

- FAA's continued NAS modernization efforts have many similar capability needs and technology development areas such as CNS, weather, and decision support tools. Through related technology needs, the possibility of sharing common assets (radar, communications networks, etc.) and operational dependencies, a common air and space transportation system is expected to evolve.

APPENDICES

APPENDICES

The appendices included with this report are intended to describe the state of the art and current development efforts being pursued in a variety of technology areas of particular relevance to the future development of space launch and test ranges, as noted in the ARTWG technology roadmaps. These appendices include descriptions and references to introduce and highlight the significance of many of the current technology efforts being pursued in these areas, as listed with the subfunctions in each of the sections of the report addressing the ARTWG subgroup findings.

APPENDIX A – Unmanned Aerial Vehicles (UAV's) as Mobile Range Assets

UAVs and high-altitude airships (HAAs) are examples of mobile sensor platforms that could be developed to enable automated and autonomous surveillance networks of sensors at dispersed locations, providing various types of data and multiple views of objects of interest.

Aircraft-based range assets (i.e., infrared detectors aboard surveillance aircraft, aircraft carrying optical instruments, Advanced Range Instrumentation Aircraft [ARIA] telemetry collection platforms) have been used over the past four decades to provide adequate coverage for areas of interest and line-of-sight coverage for areas that would otherwise be obscured by terrain. However, the ARIA capability was retired due in large part to its high operating costs. For instance, according to a 1997 report, it cost $960K to stage ARIA support for a single Eastern Range mission. Improved aircraft-based range capabilities being developed to support ballistic missile defense testing and UAV development - particularly the commercial interest in using extremely high-altitude, long-duration UAVs for data relay - could lead to the development of more economical solutions in the future. Couple this commercial interest in UAV applications very similar to those that could be useful as part of a mobile range architecture with the $1B investment DoD is making in UAV development in FY 2003 alone and this approach begins to look more attractive and realistic to consider for the mid- to far-term future.

For the future, there appears to be some promise in developing lower-cost range capabilities, both fixed and mobile, as a result of substantial multibillion dollar investments by DoD in missile defense and UAV development for various sensors and even weapons delivery. NASA and commercial interest in advancing UAV technology to demonstrate extremely long-duration, high-altitude platforms could lead to future capabilities that may compete quite attractively on price with other space-based, fixed-location, vehicle-based, or relocatable options.

UAVs could be viewed as potential future low-cost platforms for carrying mobile range instrumentation to locations where capabilities are needed, either to supplement other range capabilities or to bring range coverage to areas without other coverage.

<u>DoD UAVs</u>

UAVs have been used successfully in several recent operations, including Operation Enduring Freedom and Operation Freedom Iraq, by identifying, tracking, and designating fixed and mobile targets in Afghanistan, Iraq, and other countries using a variety of video and synthetic aperture radar sensors. For instance, DoD's Global Hawk integrated surveillance payload includes electro-optical, infrared, and synthetic aperture radar sensors, and the Air Force is interested in adding signals intelligence sensors to it as well.

Given the current intense focus and attention on UAVs based on their success in the war on terrorism in Afghanistan and other parts of the world, UAVs could be viewed as potential future platforms for carrying mobile range instrumentation. Even today's UAVs are designed to carry instrumentation and sensors with capabilities that could be useful to augment range capabilities, and future developments could yield even more suitable solutions. Potential range applications for UAVs include carrying instrumentation and sensors to provide various types of remote sensing for area surveillance, which could include detection and tracking of mobile targets in the air or on the ground, and for telemetry acquisition and communication relay.

The DoD budget for FY 2003 includes well over a billion dollars in funding relating to UAVs, and UAVs will annually be considered among the highest priority "transformational systems" in the DoD budget. In FY 2003, the DoD budget includes nearly $5 billion for such "transformational systems." In a March 28, 2002, interview with the Wall Street Journal, Under Secretary of Defense for Acquisition, Technology and Logistics (USD) (AT&L)) Edward C. "Pete" Aldridge responded to a question as to "where are the biggest leaps ahead" in terms of transformation in the President's FY 2003 budget request for DoD. In his reply, the first capability he mentioned was the emphasis on UAVs as "a high-priority area" being pursued in the FY 2003 budget for DoD.

Over the years, DoD has spent more than $6 billion on UAVs, and it has less than 100 vehicles in service.[8] Lower prices per vehicle are of great concern to DoD, and several efforts are underway to address this concern. UAV industry officials have noted that higher production rates are key to reducing the price per unit to as little as half its current level.

USD(AT&L) in March 2002 issued an acquisition decision memorandum[9] to modify the spiral development program for the Global Hawk UAV, including a procurement contract to buy 17 more in FY 2004, bringing the Air Force fleet to a total of 21. Full-rate production is scheduled to begin in FY 2006.

The Air Force has bought three Global Hawk UAVs with 2,000-pound payload capability carrying electro-optical, infrared, and synthetic aperture radar (SAR) sensors. A fourth has been built but not yet delivered, and DoD has approved low-rate initial production of 17 more before full-rate production begins in FY 2006[10]. The full-rate production rate is planned at four per year. The current price of an aircraft, a ground station, and the integrated sensor suite is about $48 million, but the Air Force has asked the manufacturer, Northrup Grumman, to reduce the cost by 25 to 50%[11] to $35 to $40 million each. If nonrecurring costs to date are spread over the few production units, the cost per unit rises to $70 million each. Northrup Grumman has suggested that the most effective way to bring down the unit cost is to raise the production rate. The manufacturer of the integrated sensor suite, Raytheon, indicated that the current unit cost is about $12 million each, but that it could drop to less than $6 million each if the Air Force were to increase the production rate to 10 per year versus the one or two per year being bought today[12].

In a June 13, 2002, the Assistant Secretary of the Air Force for Acquisition, Marvin Sambur, identified five programs including the Global Hawk UAV and the Unmanned Combat Aerial Vehicle (UCAV) as "Pathfinders" for acquisition streamlining and spiral development so they can "field key capabilities as quickly as possible."[13] In July 2002, the Air Force indicated it was considering a $750 million reduction in its planned FY 2007-2009 funding for Global Hawks due to anticipated cost savings, but such a cut may prove controversial with the Office of the Secretary of Defense, which added $300 million to the Air Force Global Hawk budget in FY 2002.[14] Also in July, the Secretary of the Air Force, James Roche, noted that he "wants the service and industry to devise new and imaginative ways to fully exploit its potential. Roche says he wants to see the system's designers adopt a fresh perspective on how to employ the Global Hawk UAV that transcends the mindset that it must represent an unmanned version of the U-2 high-altitude reconnaissance aircraft."[15]

In January 2003, DoD approved the Air Force Global Hawk production plan through 2011, at an average cost of $57 million per copy (or $37 million, without including the amortized nonrecurring research and development costs). This plan includes producing 51 Global Hawks, including 19 as low-rate production assets, four aircraft per year in FY 2004 and 2005, five in 2006, and seven in FY 2007 and 2008, and six per year for the following three years.

There is hope that production rates could increase further. The Navy is buying two Global Hawks in FY 2003 to evaluate the utility of long-endurance UAVs to supplement its maritime patrol aircraft fleet. Japan and Germany may also become interested as a result of planned demonstration flights in Asia-Pacific and European areas.

In fact, an independent analysis by Frost & Sullivan of potential future UAV markets worldwide predicts growth from $1.1 billion per year currently, to more than $1.8 billion by 2007, with the U.S. accounting for 55% of the forecast demand, Europe (mainly France) 20%, Asia (mainly Japan) 14%, and the Middie East/South Asia 10%.[16]

Of the 65 Predator UAVs the Air Force has bought, 22 have been lost to malfunctions, hostile action, human error, and weather[17]. Predators have been used in hostile environments in Kosovo, Iraq, and Afghanistan. Before operations began in Afghanistan, the Air Force was buying seven or eight Predators per year at about $4.5 million per copy, but production rates are scheduled to triple to 24 per year over the next two years. The Air Force Safety Center noted the accident rate for Predator in FY 2002 was 30 times higher than aircraft with a pilot on board.[18] Based on FY 2002 data, that results in a projected average of 45.3 mishaps per 100,000 flight hours (or 41.3 based on the Predator's 31,503 lifetime flight hours since 1997) versus 1.52 for aircraft with pilots on board. The Air Force hopes it can reduce the mishap rate for Predator by giving Predator pilots more situational awareness (e.g., posting observers on the runway during landings) and experience by extending their assignments beyond the two-year limit that has been the norm so far.

The Air Force is also planning to build an upgraded Predator B, with the same 24-hour endurance, but a 750-pound internal payload capability (versus 450 pounds for Predator A) plus 1,000 pounds of externally mounted payloads, a faster cruising speed (i.e., 210 vs 118 knots), and a higher ceiling altitude (i.e., 45,000 feet vs 25,000 feet)[19]. In the meantime, DoD plans early next year to demonstrate the use of an alternative payload, called the Predator Infrared Airborne Narrowband Hyperspectral Combat Assessor (PIRANHA), which could be used to detect and track chemical vapors after a U.S. attack on suspected chemical or biological weapons facilities.[20] Another similar capability called the Domestic Chemical Assessment System is planned to begin operational use aboard Predators starting in 2003 to detect chemical vapors in U.S. urban areas, as needed. These are included here to illustrate examples of new and innovative uses of UAVs.

Another example of a DoD UAV-based concept that could be useful for area surveillance on ranges is envisioned as part of the Air Force's Integrated Base Defense Security System (IBDSS) for physical security.[21] This concept includes detecting, tracking, and destroying enemy targets using remote weapons as far as five miles from the base perimeter using a network of infrafred, chemical/biological, and seismic ground sensors in conjunction with wideband radar and airborne sensors on a small stealthy UAV. For instance, a Desert Hawk UAV is already being used this way at an Air Force Base in the Persian Gulf, according to Col. Howard Borst, the

Force Protection Command and Control (FPC2) program manager at Hanscom Air Force Base, MA.

The Air Force is also interested in UAVs with longer endurance than current systems, and Senator John Warner (R-VA), Chairman of the Senate Armed Services Committee, has indicated he would like the military to replace one-third of its tactical aircraft and ground combat vehicles with unmanned systems over the coming decade.[22] In fact, in late 2002, the Air Force and Navy were considering cutting the numbers of planned aircraft procurements to make room in their budgets for plans to spend up to $2 billion on unmanned combat aerial vehicles (UCAVs) between FY 2004 and 2009.[23]

While questions have been raised as to the operational effectiveness of the current Predator and Global Hawk UAVs deployed in Afghanistan due to their sensitivity to operating in adverse weather and their limited ability to remain on station, there is also promise in some of the technology NASA has demonstrated for future UAVs with potential commercial applications.

<u>NASA and Commercial UAVs</u>

NASA has for years been working to develop and demonstrate UAVs, with emphasis on expanding the flight envelope to include ultra-high altitude and endurance capabilities. (Global Hawk UAVs typically fly reconnaissance missions at 60,000 feet altitude; NASA UAVs have flown to nearly 100,000 feet altitude.) Some of these UAV capabilities have generated commercial interest because of their potential to be used as platforms for communication relay equipment and other instrumentation that could potentially be useful as range assets.

For instance, NASA is developing and demonstrating technologies to enable a variety of UAVs to operate at extremely high altitude and for extended duration. In fact, NASA Wallops Flight Facility compiled a list in 1999 of 45 U.S. UAVs in development[24] with various levels of payload weight, altitude limits, and flight duration in three categories: (1) local (i.e., < 50 km range), (2) regional (< 200 km), and endurance (> 200 km). Seven of these vehicles are capable of carrying more than 700 pounds of payload, and eight of them (including three that can carry heavy payloads) are capable of flying more than 24 hours at a time. In the near-term, these UAVs will drive demanding test requirements, particularly in terms of geographic coverage areas. For instance, according to Jerry McKee, Program Manager for the Western Aeronautical Test Range at NASA's Dryden Flight Research Center, California, the Altair UAV will have a test requirement to fly from California to Alaska. Similarly, the Global Hawk UAV has undergone test flights from California to Australia.

As particularly interesting examples of the UAV technology NASA is pursuing, the solar-powered Pathfinder, Centurion, and the $15 million Helios UAVs have flown to nearly 100,000 feet altitude since 1998 as part of NASA's Environmental Research Aircraft and Sensor Technology (ERAST) program, sponsored by the Dryden Flight Research Center. The point of ERAST is to develop UAVs to inexpensively carry communication equipment and sensors to high altitudes, and keep them there, functioning much like a satellite (though at much lower cost), for extended periods of time. The August 2001 Helios flight that set the nonrocket-powered aircraft altitude record of 96,863 feet lasted 27 hours, though the craft is designed to operate at altitude for up to three months at a time using fuel cells (installed in the summer of 2003) to store the energy collected during the day to fly through the night.

According to the AeroVironment (builder of the Pathfinder and Helios UAVs) web site[25]:

> *In June and July of 2002, SkyTower and AeroVironment in collaboration with the Japanese Ministry of Post and Telecommunications (CRL/TAO) and NASA, successfully completed several telecom tests in Kauai—the world's first commercial applications transmitted from over 60,000 feet in the stratosphere. The two applications tested, HDTV and 3-G mobile, further validate the viability of the SkyTower's unmanned High Altitude Platform Station (HAPS) for use by wireless service providers for a broad range of telecommunications applications. The final test, a telecom demonstration scheduled for mid-July, provided an opportunity for participants to see this breakthrough technology first-hand.*
>
> *The commercial version of Helios, which is the ultimate evolution of the Pathfinder and Helios Prototype will incorporate a fuel cell energy storage systems to provide power for flying through the night. It will be capable of continuous flight for months at a time at altitudes of 50,000 to 70,000 feet. A full-size fuel cell and electrolyzer energy storage system for the Helios Prototype is now operating in AeroVironment's test facility. As part of the NASA ERAST program, a reduced weight version of this system will be integrated into the Helios aircraft to enable continuous multi-day flight operation.*

According to a February 3, 2002 SkyTower press release[26] regarding this summer 2002 test:

> *"The first planned telecom demo is a third-generation mobile application providing two-way data rates of up to 384 kilobytes per second to a mobile user on the ground, suitable for video transmission to a handheld device, as well as for other voice and data transmissions including Internet access," said Stuart Hindle, vice-president of strategy and business development for AeroVironment subsidiary SkyTower, Inc. "The second telecom demo is a digital high definition television application providing a picture-perfect video broadcast signal to a fixed receiver on the ground at twice the resolution of conventional broadcast transmissions."*

"Hindle noted that for the telecom applications, the Pathfinder-Plus and its on-board transceiver, flying above the weather at 60,000 feet, would act like an 11-mile tall tower in the sky, doing the function of a geostationary satellite but without the time delay. According to AeroVironment/SkyTower chief executive officer Tim Conver, just one of the firm's solar-electric aircraft could provide broadband local access services at "over 1,000 times the capacity of a typical space-based satellite, be deployed at a fraction of the cost of cable and DSL, and be set up in a matter of days."

"The Pathfinder-Plus aircraft is available as a test platform for research and development of commercial missions," Bauer added. "If the customer has the funds, we have the capability."

According to a January 30, 2002 *Aerospace Daily* article entitled "*UAVs Could Solve 'Last Mile' Problem For Ailing Telecom Industry":*

> *SkyTower's service, which should be available by the end of 2004, will use an aircraft derived from the Helios, which has a wingspan of 256 feet, and will be comparable in size. . . . Despite their size, AeroVironment's aircraft can take off at bicycle speeds in distances less than their wingspans. "The airplane actually could take off and land even from a dirt field," Hindle said.*
>
> *"If you look at it from a deployment perspective, it's a fraction of the cost to deploy on a dollar-per-bit-per-second, [or] dollar-per-subscriber basis, compared to cable, DSL, [or] satellite," Hindle told The DAILY. "It can be launched in a matter of days, as opposed to weeks or months, with conventional systems."*
>
> *UAVs also offer great advantages in data throughput, according to Hindle, due to their proximity to the Earth, which allows higher levels of frequency reuse. "On a bit-per-second-per-square mile basis, just a single platform of ours can provide over a thousand times the capacity of a satellite for local-access coverage," he said.*
>
> *Once it reaches its final altitude, the UAV can fly slow circles or figure eights in an area so small that it essentially behaves as a geostationary point in the sky, allowing it to communicate with fixed antennas on the ground, according to Hindle. [A] single UAV could cover an area up to 600 miles in diameter, . . . [and] on the ground, a gateway station would communicate with the deployed UAVs, linking them with the public telecommunications switching infrastructure, as well as the Internet.*

For at least two years, Boeing has also been working on an ultra-long-endurance UAV (ULE-UAV) with a 100-foot wing span, 60,000 to 75,000-foot operating altitude, payload of "a couple hundred pounds," and a hydrogen fuel cell that expels only water vapor to power its electric motors to turn its propellers.[27] Potential applications include area surveillance for homeland security (i.e., harbor and border patrol) or as a communication relay platform. Boeing anticipates such a vehicle could be flying by 2005.

Finally, another example of NASA UAV-related activity involves flight tests starting in April 2003 at Dryden Flight Research Center to demonstrate the capabilities of a lightweight 35-GHz airborne collision avoidance radar system for use aboard UAVs to detect uncooperative aircraft (i.e., without transponders) to help enable regulatory approval for UAV flights in U.S. airspace.[28] Such a capability could have obvious applications for area surveillance.

Potential Civil and Homeland Security Uses for UAVs

There is some interest in using UAVs in U.S. airspace for a variety of civil and homeland security tasks including moving cargo, pinpointing traffic problems, patrolling borders, searching for fugitives, and fighting forest fires.[29] UAVs today are flown infrequently in U.S. airspace for testing, but such flights require FAA approval (requiring about two months lead time) with restrictions to controlled airspace and sometimes requiring use of expensive chase aircraft to accompany them. Some in industry have advocated a five-year plan where FAA would initially include stringent rules to allow UAVs to fly above airline traffic (i.e., above 40,000 feet altitude) but with reduced restrictions over time.

In December 2002, Senator John Warner (R-VA), Chairman of the Senate Armed Services Committee, expressed interest in requesting that the President appoint a committee to explore the use of UAVs by civil agencies including the Border Patrol and the Coast Guard.[30] As further examples, the Department of Transportation noted it has been working with NASA for more than four years to use UAVs to monitor traffic flow, monitor trucks carrying hazardous cargo, and monitor oil and gas pipelines.

The Coast Guard hopes to acquire 76 vertical-takeoff, tilt-rotor Eagle Eye UAVs (built by Bell Helicopter Textron) for use nationwide as part of a 20-year, $17 billion program called "Deepwater," which also includes new aircraft, a new cutter, modifications to helicopters, and new surveillance equipment.[31]

APPENDIX B – High-Altitude Airships (HAAs) as Mobile Range Assets

As is true of UAVs, there is also a high level of interest within DoD (specifically, North American Aerospace Defense Command [NORAD], the Army, Navy), as well as the Coast Guard, the Federal Aviation Administration, the Department of Homeland Security, and the commercial sector in HAA applications and capabilities as instrumentation or data relay platforms.

HAAs could provide similar mobile range capabilities to UAVs, and Government and commercial entities are similarly expressing interest in developing airships for various, somewhat related capabilities that could be leveraged to provide future range capabilities.

For instance, NORAD and the Army are pursing an advanced concept technology demonstration (ACTD) to procure and test a single airship as a platform to demonstrate the ability of such platforms to enhance air traffic surveillance capabilities over North America[32]. The operational concept for 2010 and beyond would include 10 airships (500 feet long, 250 feet in diameter, with a 4,500-pound payload) flying at 70,000 feet altitude around the perimeter of the continent to provide the type of coverage NORAD desires for homeland security. (Lower-altitude tethered blimps, or aerostats, are deployed and in use along the southern border of the U.S.) One 300-foot long, 90-foot diameter "stratoship" capable of carrying a 500-pound payload is being proposed for FY 2003 ACTD funding, to be followed by two of the larger operational airships. NORAD acknowledges that the airships could have "broader applicability" and last year, the Army's Space and Missile Defense Command issued a "request for information" relating to such high-altitude airships.

According to the September 2002 Presolicitation Notice issued by the Missile Defense Agency[33],

> *The Department of Defense (DoD) has identified a requirement for the design and production of a Lighter than Air, High Altitude Airship Advanced Concept Technology Demonstration prototype (HAA-ACTD). The objective of this ACTD is to demonstrate the engineering feasibility and potential military utility of an unmanned, un-tethered, gas filled, solar powered airship that can fly at 70,000 ft. The prototype airship developed under this effort will be capable of continuous flight for up to one month while carrying a multi-mission payload. This ACTD is intended as a developmental step toward an objective HAA that can self deploy from the continental United States to worldwide locations.*

The accompanying Industry Day briefing by the Missile Defense Agency[34] noted that the objectives for the ACTD are to advance the technologies for an HAA system and to fly a prototype to demonstrate that the technologies demonstrated can evolve from this ACTD to an operational system that will:

- Accommodate and power a heavier payload (i.e., up to 12,000 pounds versus the 4,000-pound payload for the ACTD) with greater power demands (i.e., > 75 kW versus the 15 kW power to the payload for the ACTD).

- Operate autonomously in the stratosphere (i.e., 70,000 to 80,000 feet altitude) for sustained, long-endurance (longer than one year) operations. (The ACTD must demonstrate station-keeping for one month, within 2 kilometer lateral excursion, and maximum 100-kilometer excursion due to high-wind events, up to 45 knots continuous or 100 knots for a week. For the ACTD, the airship must be controllable anywhere in the world using a joint-interoperable, encrypted command and control system to operate the airship from a command center in the United States.) Both the ACTD and operational system must include a nonexplosive flight termination system for safety.

- Perform as a stable, geostationary communications, sensor, and weapons platform, transmitting telemetry data to the ground from onboard sensors.

The ACTD is to include three demonstration flights, in August 2004 (to demonstrate low-altitude flight for hours, demonstrating launch, command and control, and recovery), in November 2004 for days at 70,000 feet altitude to demonstrate the operation of a communication relay payload, and in spring 2005 for 30 days at 70,000 feet to demonstrate station-keeping and payload operation, in addition to launch, command and control, and recovery.

According to a March 2003 update briefing by the Missile Defense Agency[35], three industry partners are developing early concept definition designs for the ACTD. The briefing also expands on the description of the HAA operational utility by citing homeland defense missions, missile defense, and support roles for combatant commanders (NORAD, PACOM, CENTCOM, and USFK) in conducting regional conflicts and special operations worldwide.

Similarly, the Naval Air Systems Command is proposing an ACTD for FY 2004 to develop a large hybrid airship that could carry up to 30 tons of cargo (one to be configured as a surveillance platform), as a demonstration of technologies that could lead to an aircraft-carrier-sized vehicle that could carry up to 500 tons of military cargo directly from a home base to a theater of operations.[36] A hybrid airship is a buoyant helium-filled craft that also has a wing shape so it can produce lift during flight up to speeds of 80 to 90 knots. Interestingly, this ACTD is being proposed by the same Navy organization that is responsible for the Littoral Airborne Sensor Hyperspectral (LASH) airship program, which recently completed a series of flight tests at Patuxent River, MD, to demonstrate its potential in support of homeland security.

The FAA is also interested in the potential of such airships for air route surveillance over the United States and Canada. In fact, $3 billion is planned for improving U.S. and Canadian airspace surveillance between now and FY 2006, including a service life extension program for 68 old FAA radars (some that are 50 years old), a replacement program, and some research and development activities to explore the potential of an airship that would fly in the stratosphere for weeks or months at a time, advanced over-the-horizon radars, and multistatic passive systems.[37] (Interestingly, the Department of Transportation has determined that 15,600 air traffic controller positions are not inherently governmental - a change from the view expressed in a past Administration Executive Order - but they will not be subject to immediate competitive outsourcing.[38])

APPENDIX C – Signal Processing Techniques and Technologies

Signal processing to compress digital data streams and detect and correct errors can address the bandwidth and data rate demands associated with acquiring accurate tracking data through telemetry streams. Various advanced signal processing techniques and approaches could be pursued to make more efficient use of frequency spectrum and address the absorption and attenuation problems associated with the use of higher frequencies for telemetry transmissions.

For example, advanced equalization techniques can be used to improve the quality of the signal being transmitted (i.e., lowering the bit error rate). According to a paper entitled "Equalization Techniques in Communications"[39] by Kromos Communications, Incorporated of Fremont, California:

> *"The capacity of any communication system is limited by power and spectrum. As a given system is asked to carry more information, driven by the overall increase in demand for data, either the power or the spectrum allocated to the system need to increase. Practical limitations on power mean that communication system designers have to try to pack as much information as possible, i.e. as many symbols as possible, into each Hertz of spectrum available. This leads to inter-symbol interference, which reduces the quality of the received signal, as measured by bit error rate (BER). . . . Improving the quality of the signal received calls for equalization techniques, which compensate for the effects of inter-symbol interference (ISI).*
>
> *Standard equalization techniques start by modeling a communication channel as a filter, with a specific transfer function. The equalizer, which is part of the receiver, then estimates the parameters of this (unknown) transfer function, and attempts to undo the effects of this transfer function. Thus the equalizer is also a filter of a special kind."*

Various advanced equalization techniques are being pursued and developed in the commercial sector for a wide variety of communication applications relying on copper wire, fiber optic, and wireless connectivity. Much of this work is being pursued to improve fixed point-to-point communication applications. Hinton's article points out the need to extend the current research and development to mobile platforms as a means of proving its applicability to future range telemetry systems and capabilities.

Advanced modulation techniques can also be used to make more efficient use of frequency spectrum than the traditional pulse-code modulation (PCM) technique used for telemetry on ranges, with continuous phase frequency shift keying (CPFSK). One example of such an advanced modulation technique is Feher's patented quadrature phase shift keying (FQPSK-B)[40]. PQPSK-B is included in the May 2001 Inter-Range Instrumentation Group (IRIG) Telemetry Standard 106-01 as a more efficient option that is now available to range users. FQPSK-B is a patented technique, but range users can make arrangements to use it under license from Digicom, Incorporated. To illustrate the advantages of such advanced modulation techniques, the May 2001 IRIG Telemetry Standard 106-01 notes that "With a bit rate of 5 Mbps and a transmitter power of 5 watts the –25 dBm bandwidth of an NRZ [non-return-to-zero] PCM/FM system with near optimum parameter settings is about 12.8 MHz, while the –25 dBm bandwidth of an equivalent FQPSK-B system is about 7.1 MHz." In this example, using the FQPSK-B advanced modulation technique results in a need for only 55% as much frequency spectrum to transmit telemetry at the same data rate and power.

Advanced error correction techniques can also lead to more efficient use of higher frequency spectrum for telemetry. For example, error-correcting Turbo codes (i.e., a combination of two simple encoders whose coupled performance mimics the superior performance of random block codes but without the complexity or development expense) can be used to maintain the quality of telemetry data at a specified bit error rate with weaker signal strength. Such error-correction codes have been developed and used by NASA's Jet Propulsion Laboratory (JPL) to receive telemetry with extremely low signal strength and low signal to noise ratios from its interplanetary space probes.[41] Many commercial Turbo codes are available today[42] and could contribute to improving the ability of future ranges to use higher frequencies (with attendant lower signal strength) for telemetry.

Error Correction Techniques

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Data Compression Techniques

A variety of recent press reports have pointed to the fact that DoD has been experiencing operational limitations in its ability to fully use the capabilities of its Predator and Global Hawk UAVs in Afghanistan due to limited bandwidth for communication with the vehicles through satellite data links. For example, bandwidth limitations have limited the number of UAVs that can be operated simultaneously and prevented the real-time downloading of complete synthetic aperture radar (SAR) images from Global Hawk UAVs.

While the Air Force is working on new systems and capabilities like the Advanced Wideband System (AWS) as part of its Transformational Communication System (TCS) to improve its ability to handle larger quantities of data for the mid- to far-term, the UAV Battlelab at Eglin Air Force Base, Florida, is working to address this current bandwidth limitation by pursuing three data compression approaches to make significantly more efficient use of the spectrum available for communicating with these vehicles[45]. The Battlelab is attempting to leverage "mature technologies and demonstrate their military utility for potential rapid fielding."[46] These same data compression techniques could have "spin-off" applicability to other range-related use of frequency spectrum. Here is a brief description of each of these initiatives:

- Digital Imagery Video Compression and Object Tracking. Using commercial data-compression techniques, this initiative is being pursued to compress the

Predator UAV video signal by a factor of 10 without any loss of fidelity. Compression ratios of up to 300 or 400 to 1 are possible with a 1 to 2% loss of pixels in the video imagery data. The Battlelab is planning an initial demonstration of this technique in the summer of 2002.

- SAR Imagery Data Compression. The Battlelab has recently begun an 18-month project to explore compression algorithms to reduce Global Hawk bandwidth requirements by a factor of 10 to 20. This project is being pursued in conjunction with the Air Force Advanced Projects Office of the Aeronautical Systems Center at Wright-Patterson Air Force Base, Ohio.

- UAV-to-Fighter Imagery Relay. In December 2001, the Battlelab completed the second phase of this project, which included transmitting still video images from a Predator UAV to the cockpit of a fighter flying within line-of-sight, using UHF and VHF transmissions.

NASA JPL is pursuing Onboard Hyperspectral and Image Data Compression research and demonstrations to improve spectral efficiency, while operating robustly in the presence of channel noise. Approaches include progressive compression methods and intelligent buffer management with the objective of increasing the return of data over communication channels that are constrained by bandwidth and Effective Isotropic Radiated Power (EIRP).

Another similar project, High Performance Data Compression, is being pursued by NASA Goddard Space Flight Center, to explore a technique using enhanced discrete cosine transform (EDCT) and the 2-D Lapped Transform to provide advantages over current commercial capabilities, including no table look-up, selectable compression ratio, browsing or quick-look using an embedded bit string, and reduced reconstruction distortion.

DARPA’s Advanced Technology Office (ATO) is pursuing the Tera Hertz Operational Reachback (THOR) program to develop a mobile free space optical path that is robust, extensible, and deployable on demand, by leveraging the switching and correcting power of a network, commercial fiber optics technology, and electro-optical beam steering to overcome traditional free-space optical communications pitfalls, including line-of-sight limitations and losses through poor atmospheric conditions.[47]

DARPA's Information Processing Technology Office (IPTO) is focused on creating a new generation of computational and information systems with capabilities far beyond those of current systems. These cognitive systems will be able to:

- Reason, using substantial amounts of appropriately represented knowledge
- Learn from their experiences and improve their performance over time
- Explain themselves and take naturally expressed direction from humans
- Be aware of themselves and able to reflect on their own behavior
- Respond robustly to surprises, in a very general way

One example of a DARPA/IPTO project is the High Productivity Computing Systems (HPCS)[48] program to create new generations of high end programming environments, software tools, architectures, and hardware components with improved:

- Performance: computational efficiency
- Programmability: reduce cost and time to develop application solutions
- Portability: insulate research and operational application software from system specifics
- Robustness: improve reliability and reduce risk of malicious activities

Such capabilities could be very useful in enabling data compression and error detection/correction algorithms.

Multiplexing can also be used to increase network capacity. For instance, some networks use dense wavelength division multiplexing (DWDM), time division multiplexing (TDM), or frequency division multiplexing (FDM). Each has its own advantages and disadvantages, but multiplexing in general is one way to improve the data-rate capacity of a given communication connection.

APPENDIX D – Sensor and Object Recognition Technologies

DoD's Multisensor Command and Control Aircraft (MC2A) program is part of the Multisensor Command and Control Constellation (MC2C) program to integrate Command and Control (C2) and Intelligence, Surveillance, and Reconnaissance (ISR) capabilities, including current, developmental, and future manned/unmanned space, air, and ground sensors, data links, ground stations, exploitation tools, communication/information dissemination systems, and C2 and battle management elements.[49] The MC2A is an advanced manned aircraft program to incorporate state-of-the-art Ground Moving Target Indication (GMTI) and Air Moving Target Identification (AMTI) sensors that will be supplemented by a constellation of high- and medium-altitude long-endurance UAVs and space sensors as part of the overall MC2C architecture. MC2A and MC2C are spiral development programs and they promise to spin-off technologies and capabilities that would be very useful for area surveillance, tracking, telemetry and communication relay, and decision making support on future ranges.

<u>Optical Imaging</u>

A variety of optical imaging systems and capabilities have been developed and used for tracking and engineering sequential data on space launch and test ranges, and others have been proposed to improve such capabilities. For instance, the HALO-I and II airborne optical instruments developed for and used by MDA are capable of imaging objects in visible, mid-wave and long-wave infrared. In April 2001, White Sands Missile Range, New Mexico, submitted a proposal through the DoD Central Test and Evaluation Investment Program (CTEIP) to develop a High-Altitude Intercept Imaging System (HAIIS) capable of measuring the impact point on the target missile during ballistic missile defense intercept test scenarios.[50] Similarly, the Naval Air Warfare Center Weapons Division (NAWCWD) at China Lake, California, proposed developing a lightweight 36-inch large aperture infrared telescope with a high-resolution mid-wave infrared camera to provide a deployable precision optical tracking system to meet the high-altitude imaging requirements associated with missile testing programs.[51]

<u>Synthetic Aperture Radar (SAR) Imaging</u>

SAR imaging data can be particularly useful in identifying objects, and NASA JPL has been operating an airborne SAR instrument (AIRSAR) aboard a DC-8 aircraft since 1988.[52]

> *AIRSAR is an all-weather imaging tool able to penetrate through clouds and collect data at night. The longer wavelengths can also penetrate into the forest canopy and in extremely dry areas, through thin sand cover and dry snow pack. . . . AIRSAR serves as a NASA radar technology testbed for demonstrating new radar technology and acquiring data for the development of radar processing techniques and applications.*

According to NASA JPL:[53]

> *For an imaging radar system, about 1500 high-power pulses per second are transmitted toward the target or imaging area, with each pulse having a pulse duration (pulse width) of typically 10-50 microseconds (us). The pulse normally covers a small band of frequencies, centered on the frequency selected for the radar. Typical bandwidths for an imaging radar are in the range 10 to 200 MHz.*
>
> *Synthetic aperture radar is now a mature technique used to generate radar images in which fine detail can be resolved. SARs provide unique capabilities as an imaging tool. Because they provide their own illumination (the radar pulses), they can image at any time of day or night, regardless of sun illumination. And because the radar wavelengths are much longer than those of visible or infrared light, SARs can also "see" through cloudy and dusty conditions that visible and infrared instruments cannot.*

NASA has also operated SAR imaging systems in space, including the SIR-C/X-SAR (Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar) which flew aboard the Space Shuttle (STS-59 and STS-68) in April and October 1994. In February 2000, NASA flew the Shuttle Radar Topography Mission (SRTM) to produce a radar map of the Earth with unparalleled resolution and precision.

Passive Coherent Locator Technology

Another potential area surveillance capability for the future is passive coherent locator (PCL) technology (see Figures D-1, D-2, and D-3). Passive coherent locator technology is a method of receiving and processing multipath interference patterns among commercial FM radio and television broadcast signals to calculate and display the position and velocity of vehicles in flight. Lockheed Martin has more than 20 years of history in pursuing passive coherent location technologies, including nonreal-time and real-time, narrow- and wide-band systems.

Through a series of experiments in the late 1990s, Lockheed Martin demonstrated the use of its Silent Sentry PCL system to collect data from multiple wideband illuminators to perform real-time aircraft tracking and narrowband sources to provide nonreal-time trajectory calculations.

Nominal Accuracy	With 1 Illuminator	With 2 Illuminators	With 3 Illuminators	With 4 Illuminators
Position (horizontal)	500 m	150 m	120 m	100 m
Position (vertical)	300 m	150 m	130 m	100 m
Velocity (horizontal)	50 m/s	< 2 m/s	< 2 m/s	< 2 m/s
Velocity (vertical)	--	--	12 m/s	7 m/s

Figure D-1 Passive Coherent Locator – Real-Time Aircraft Tracking Accuracy at 30-km Range

Nominal Accuracy	With 1 Illuminator	With 2 Illuminators	With 3 Illuminators	With 4 Illuminators
Position (horizontal)	2000 m	400 m	250 m	220 m
Position (vertical)	1000 m	650 m	550 m	500 m
Velocity (horizontal)	100 m/s	< 2 m/s	< 2 m/s	< 2 m/s
Velocity (vertical)	--	--	11 m/s	7 m/s

Figure D-2 Passive Coherent Locator – Real-Time Aircraft Tracking Accuracy at 100-km Range

In 1997, Lockheed Martin demonstrated the use of its Silent Sentry PCL system to track U.S. Air Force expendable launch vehicles. In 1999, Lockheed Martin demonstrated its ability to track NASA's Space Shuttle during launch and landing to a range of 600 km.

Nominal Accuracy	Post-Processed
Position (horizontal)	20 m
Position (vertical)	20 m
Velocity (horizontal)	1 m/s
Velocity (vertical)	1 m/s

Figure D-3 Passive Coherent Locator – Nonreal-Time Space Launch Tracking Accuracy

PCL systems can provide tracking for launches of missiles, expendable launch vehicles, the Space Shuttle, aircraft surveillance, and target position and velocity estimates. However the demonstrated levels of accuracy indicate that PCL technology may be better suited to area surveillance for the ranges than to precise metric tracking. Lockheed Martin is pursuing a variety of potential applications for its Silent Sentry PCL capability and is working to develop a third prototype that can provide continuous area surveillance and aircraft tracking at up to 50 nautical miles in range (using a small deployable antenna) with electronic equipment that can be deployed four 150-pound shipping containers (see Figure D-4).

Lockheed Martin's van-based Silent Sentry 2 PCL prototype consists of several racks of equipment in a van with multiple antennas. It has been used in real-time demonstrations to track multiple aircraft, ELV launches, and Space Shuttle launch and landing operations.

Figure D-4 Lockheed Martin's Silent Sentry

Hyperspectral Sensors for Airborne Platforms

Hyperspectral sensors aboard airborne platforms could be of particular use on space launch and test ranges in identifying and tracking the composition and concentration of hazardous vapors in clouds that result from accidental propellant spills or vehicle destruction in flight.

Through the 1980s and 1990s, NASA JPL developed and used several instruments, including the Airborne Visible/InfraRed Imaging Spectrometer (AVIRIS) and Hyperspectral Digital Imagery Collection Experiment (HYDICE), optical sensors that fly aboard aircraft and deliver calibrated images based on molecular absorption and particle scattering signatures in hundreds of spectral bands. Research with these systems has focused on the environment and climate change but the hyperspectral sensor and data processing approaches could be applied to hazardous vapor detection, identification, and monitoring on space launch and test ranges.

LIDAR Systems

Distance LIDAR is an acronym that stands for Light Detecting And Ranging, as radar is a word derived from an acronym for radio detecting and ranging. As with radar, LIDAR can be used to measure the distance to an object, its speed, and its orientation or rotation. Unlike radar, LIDAR can also be used to measure the chemical composition and concentration of chemicals in diffuse clouds or smoke plumes.

LIDAR has a variety of potential applications on space launch and test ranges, from surveillance through clouds, to tracking of flight vehicles and debris after flight vehicle destruction, to characterization of toxic vapor clouds after accidental spills involving volatile hazardous commodities like hypergolic propellants.

The Chemical Dynamics Branch of the Atmospheric Sciences Division NASA Langley Research Center has included a LIDAR applications group since 1978.[54] For instance, it has used LIDAR in ground-based, airborne, and Space Shuttle instruments to detect and measure ozone, aerosols, pollutants, and water vapor in the Earth's atmosphere at many locations around the world.

The University of Wisconsin is working to develop high spectral-resolution LIDAR systems using two signals that can be processed to yield separate returns for aerosol and molecular scattering of laser light.[55] This can be particularly useful in characterizing the composition and concentration of toxic vapor clouds that disperse in the atmosphere after propellant spills or launch vehicle destruction in flight.

Differential Absorption Lidar (DIAL) is a method using two signals of different frequency and/or polarization to identify gaseous and aerosol constituents and position. This method was used operationally at KSC as early as STS-3.

Pulsed LIDAR can be used detect and track objects through clouds, fog, or smoke (e.g., from launch vehicle exhaust), a particularly useful function for space launch and test ranges. For instance, since the summer of 2001, the Air Force Space Battlelab, in conjunction with the Air Force Research Labs, General Atomics Corporation, Boeing-SVS, Inc., and MacAulay-Brown, Inc., are demonstrating a day/night, all-weather LIDAR imaging capability comparable to forward-looking infrared or standard visible imagery.[56] This system, called Combat Eye, uses eye-safe short-pulse lasers (and gating of scattered radiation) to illuminate target areas through clouds to demonstrate a significant improvement over current space-based imagery systems. This system was demonstrated on a C-130H flight in September 2002, but the LIDAR system can be adapted to fly aboard other aircraft as well.

Meanwhile, the Missile Defense Agency's Advanced Systems Office is planning a major effort next year to develop and use LIDAR for better target tracking.[57]

<u>Object Recognition</u>

Since 2001, DARPA's Information Exploitation Office (IXO) has been pursuing the development and demonstration of precision identification of moving and stationary tactical targets from standoff platforms by electro-optical sensors working in conjunction with air-and space-born radar sensors.[58] Using radar data for initial detection and tracking, the Eyeball sensor combines spatial, spectral, and polarimetric signatures to enable real-time precision identification of targets. Polarimetric (or dual-polarization) signatures are based on radio wave pulses that have both horizontal and vertical orientations.

DARPA IXO and the Missile Defense Agency (MDA) have also pursued other projects addressing automated target identification. One example is DARPA's Video Verification of Identity (VIVID) pattern recognition project, which is scheduled to begin (after source selection) in June 2003. The VIVID program goal is to provide an automated means of moving target verification using airborne video data sources.[59] According to DARPA's technical description of the project:

> *VIVID will focus on developing new technology to track, ID and strike moving targets using visible and infrared video data sources, and to do so under challenging conditions involving dense, urban traffic and frequent occlusions. This will require the handoff of the target from a broad-area surveillance cue, real-time geolocation and automated tracking to keep the sensor and a laser designator on target until weapon impact. Current generation video trackers lose track frequently when moving targets are temporarily occluded, shadowed, or in close proximity. VIVID will solve this problem by incorporating ID confirmation within the tracking loop.*

One technical objective of the VIVID project is to provide "confirmatory ID" of objects of interest. The project may involve matching objects to appearance data (e.g., 3-D models), but it must be able to create its own model from initial observations, and account for:

- Pose, or orientation, as objects are observed from various elevation angles and headings
- Illumination, or changes in the angle between the sun and the video sensor line of sight
- Shadows, as a moving vehicle may move in and out of shadows
- Articulations, or changes in the orientation of moving parts
- Occlusion, or partial obscuration by buildings, trees, other vehicles, clouds, or terrain

In pursuit of somewhat similar objectives, as part of its Intelligent Systems & Robotics work, Sandia National Laboratories has been developing Visual Object Recognition technologies and systems to identify objects regardless of orientation, background clutter, overlapping objects, and lighting variations.[60] This system includes software that allows the system to train itself to recognize new objects by picking out and identifying up to 5,000 identifying features from training images that are input to the system. The program has been demonstrated to identify objects in less than one minute on a personal computer. Variations of the identification algorithm have been demonstrated in far-reaching applications, from finding military vehicles in photographic images to identifying infant car seats in automobiles to prevent the air bag from deploying.

APPENDIX E – GPS Upgrades and Supplements

U.S. space launch and test ranges are in the process of making more regular use of GPS for metric tracking, with DoD providing the primary source of funding to upgrade range capabilities and reliable onboard flight systems. For instance, while the Air Force plans to eliminate three radars from the Eastern Range and eight from the Western Range as it migrates to GPS metric tracking, it will still also maintain a few radars (i.e., one multiple-object tracking radar [MOTR] at each range, plus three metric tracking radars at the Eastern Range for Space Shuttle launch and landing support, and three radars at each range for ballistic and space object tracking). In parallel, the Air Force is funding the development and certification by 2007 of GPS receiver systems for the Evolved Expendable Launch Vehicle (EELV) program. Both ranges support ballistic missile test flights today with GPS translators, and the Western Range is scheduled to be ready to support Minuteman III test flights with GPS receivers by 2004. Before eliminating tracking radars, all vehicles flying on the ranges must be ready to use GPS metric tracking instead.

One concern with regard to relying on GPS signals for tracking of launch and flight test vehicles on ranges is that GPS signals are low powered and vulnerable to spoofing, jamming, and interference. Jamming equipment can be cheap and easy to build, and GPS jamming equipment already exists.[61] In March 2003, during the height of Operation Iraqi Freedom, President Bush made a phone call to Russian President Vladimir Putin to express his serious concern regarding the sale of GPS jamming equipment to Iraq by Russian companies.[62] According to a Washington Post article, "U.S. officials said they are furious that the Russian government has not stemmed the sales, despite repeated requests over the past year to take action."[63] Several approaches are being pursued to address this vulnerability and each could be used or adapted for use on space launch and test ranges. Specifically:[64]

> *The GPS Joint Program Office established the Navigation Warfare (NAVWAR) program in 1996 to address the electronic warfare threat to the GPS system. The NAVWAR program was tasked with protecting DoD and allied use of GPS during times of conflict, preventing its use by adversaries, and maintaining normal availability to the civil user outside the area of conflict. The primary near-term solution to meet NAVWAR objectives involves fielding anti-jam antenna systems on weapons platforms. The present anti-jam antenna system in production, GPS Antenna System-1 (GAS-1), is an analog system with anti-jam capability limited to the formation of spatial nulls in the direction of interference. Over 1,000 units of the GAS-1 have been produced by Raytheon Systems Limited, in Harlow, UK. The GPS roadmap for user equipment anticipates a fully digital receiver with nulling/multi-beam steering as a long term solution.*

To improve on the GAS-1 capability, Raytheon is working to develop next-generation anti-jam technology for military use of GPS. One element of this effort is the U.S. Navy's Space & Naval Warfare Systems Center's Digital Antenna Electronics (DAE) program for GPS anti-jam research and development.[65] These technologies (including a combination of innovative system architectures, null-steering, limited beam-forming, and advanced signal processing techniques) must be compatible with current GPS receivers in use aboard DoD aircraft and future GPS signal structures, such as M-code and spot beam modes. DAE offers a major near-term improvement by using digital signal processing to enhance jammer suppression by providing a limited beam steering capability to assist in filtering out jammer noise, while preserving the current GAS-1 form, fit, and interfaces.

As previously noted, future GPS signal structures, such as the M-code and spot beam modes offer higher power signals and more jam-resistance. Another approach to increasing the jam-resistance of GPS signals has been taken by the FAA for safety-of-life air navigation systems relying on GPS. FAA has deployed ground equipment (known as pseudo-lites) to augment the GPS signals with corrections based on the known locations of these ground transmitters. This supplemental system is known as Local Area Augmentation System (LAAS), and more precise versions are known as differential GPS (DGPS), which are currently deployed along the U.S. coasts and planned for deployment natinowide. Such systems already exist at the nation's major space launch and test ranges. FAA has also leased transponders on commercial satellites to provide a wide area augmentation system (WAAS) for GPS.

One of the most significant projects underway within FAA is the Automatic Dependent Surveillance (ADS)-B program to augment WAAS in Alaska, where small civil aircraft are used regularly for travel and commerce among widely dispersed settlements separated by long distances and mountainous terrain, and near Louisville, KY, where Federal Express operates its very active hub between 9 pm and 5 am every day.[66] Air route surveillance radars still provide the primary skin track data with samples collected from each sweep at 4- to 12-second intervals, but ADS-B transponders are being demonstrated as secondary tracking systems, providing data at one sample per second, to report heading, altitude, speed, call sign, distance, and aircraft type. Today, 190 aircraft in Alaska are equipped with ADS-B transponders, GPS receivers, and flat panel displays that are also used for weather data. In the current phase of testing, 14 coastal ground sites for broadcast, receive, and voice communication are being installed around Juneau. In the subsequent phases, FAA plans to deploy ADS-B statewide in Alaska and eventually in the lower 48 states.

The Air Force Space and Missile Systems Center (SMC), Electronic Systems Center (ESC), Mitre, and the Aerospace Corporation are researching the cost-effectiveness of various approaches to augment the GPS constellation to fulfill a variety of communications requirements under a study effort called the Global Multimission Support Platform (GMSP).[67]

APPENDIX F – Low Power Transceivers

DoD's Joint Tactical Radio System (JTRS) is a transformational program intended to provide a family of software programmable radios for reliable multichannel voice, data, imagery, and video communications as part of a Software Communications Architecture (SCA).[68] JTRS is being designed to be modular, scaleable, backward-compatible with the legacy radios, network-capable, and interoperable. Such a capability could find applications in other areas, including homeland security, law enforcement, search and rescue, commercial aviation, international commercial uses, and of course, range support.

NASA Goddard Space Flight Center is pursuing low power transceiver (LPT) technology to demonstrate the feasibility of combining communication and navigation functions in a single device for NASA spacecraft, but such a device could conceivably be adapted for use aboard flight test vehicles or mobile range assets. The first-generation LPT was manifested as a Hitchhiker payload on the ill-fated Space Shuttle Columbia mission STS-107, which was lost during reentry on February 1, 2003. The LPT was to have demonstrated how TDRSS, GPS, and ground-based assets would be integrated for onboard orbit determination. It was also to have demonstrated a space-based range safety command and control concept (including simultaneous spread spectrum links from two TDRS spacecraft and a ground terminal). The second-generation engineering development model LPT is intended to also include adaptive antenna beamforming and a processing algorithm to enable formation flying by addressing interference and multipath.

Another LPT in development by ITT is a 12-channel S-band and L-band receiver and an S-band transmitter. This system will weigh 5 kg and fit in a 5-inch x 5-inch x 5-inch volume. Power required could be up to 25 watts. In a related project, NASA's Small Expendable Launch Vehicle Transmitter Project is using LPT technology to develop a 30-watt telemetry transmitter that will be compatible with TDRSS. This unit has completed preliminary design review. The data rate for the two encodable independent channels is up to 4 Mbps per channel.[69] Of course, the usefulness of these LPTs in tracking flight vehicles would be to enable the use of GPS receiver data and onboard inertial measurement unit guidance data to embed tracking data in the vehicle's telemetry stream, which could be relayed through space-based or mobile platforms to control centers on the ground for further processing and display.

NASA KSC is also pursuing a flight experiment called Space-Based Telemetry and Range Safety (STARS) to demonstrate the feasibility of using the existing space network (i.e., TDRSS) to provide a two-way communication link between a flight test aircraft or a launch vehicle and the control center. The STARS hardware includes a GPS receiver to produce tracking data that it transmits (along with onboard guidance system tracking data and other vehicle telemetry data). It also includes equipment to receive range safety commands directly from ground-based transmitters or linked through a satellite. Flight tests of the STARS system are intended to demonstrate through a series of three or four flights at NASA Dryden Flight Research Center, including dynamic maneuvers, that it can:

- Provide vehicle tracking data during flight operations over the horizon from the ground-based instrumentation near the control center

- Determine the feasibility of forward and return satellite links for real-time monitoring of vehicle telemetry (including tracking data from its onboard GPS receiver)

- Evaluate various modulation technique that make more efficient use of spectral bandwidth

- Measure data transmissions to compare with latency limits for telemetry data, command and control (C2), flight termination, and real-time video

Yet another example of a low-power transceiver that includes a GPS receiver for tracking is the Vehicle-Based Independent Tracking System (VBITS) in development by Space Information Labs. VBITS is designed to transmit tracking data as part of the flight vehicle's telemetry stream to ground controllers using a real-time S-band data link of GPS and inertial measurement unit data for direct input into range safety display systems using the existing range ground telemetry receiver interfaces. It also includes a Globalstar modem to transmit the telemetry stream through low-Earth orbiting satellites, and it can be adapted to include a transmitter capable of linking telemetry through TDRSS. VBITS includes its own fully integrated, self-contained power supply in the form of an advanced technology lightweight polymer battery. VBITS is designed to satisfy Range Commanders Council (RCC) 324-01 GPS Requirements. The system includes a universally mate-able patch-antenna system for rockets, missiles, aircraft and UAV/UCAV platforms.[70]

APPENDIX G – Enabling Use of Higher Frequencies

Today's Frequency Use on Ranges

U.S. space launch and test ranges today use three bands within the UHF portion of the frequency spectrum for telemetry[71]:

- 1435 to 1535 MHz (L band) for Government and nongovernment aeronautical telemetry on a shared basis, including launches and reentry of vehicles with or without crews while undergoing flight testing. Since 1992, Mobile Satellite Services have shared use of 1525 to 1530 MHz, and Maritime Mobile Satellite Services have shared use of 1530 to 1535 MHz.

- 2200 to 2300 MHz (S band) for telemetry associated with launch vehicles, missiles, upper atmosphere research rockets, and space vehicles regardless of their trajectories. 2290-2300 MHz is used on a shared basis for deep space missions.

- 2310 to 2390 MHz (upper S band) for Government and nongovernment telemetry on a shared basis, including flight testing of manned or unmanned aircraft, missiles, space vehicles, or their major components and for expendable and reusable launch vehicle testing and operations. 2310 to 2360 MHz was reallocated and auctioned by the Federal Communications Commission in April 1997 for primary use by Wireless Communications Service and Digital Audio Radio Satellite. 2360 to 2390 MHz is allocated for Mobile Satellite Services through 2005 and 2385 to 2390 MHz was reallocated to other applications by the Balanced Budget Act of 1997.

International Interest in Preserving Access to Spectrum for Range Use

In response to the risk that frequency spectrum for telemetry will be further reallocated, the International Consortium for Telemetry Spectrum (ICTS) was proposed in 1999 and its by-laws were established in 2001. The purpose of the ICTS is to advocate the protection of spectrum that is critical to continuing telemetry applications worldwide. Here are some of the points made by ICTS in one of its presentations in 1999[72]:

- *Spectrum is a finite resource fast approaching the Shannon limit: the point where its use is so saturated there is nowhere left to go to satisfy new or more demanding requirements.*
- *Telecommunications industries are organized to provide persuasive influence on the future global use of spectrum—space and aerospace players are not:*

  - 27% of the spectrum for TSPI and commanding has been lost since 1993

  - 61% of upper S-band for telemetry has been lost since 1992

  - 44% of L-band for telemetry has been degraded or denied due to interference
- *The amount of spectrum available for telemetry has decreased while demand has increased for higher data rates and bandwidth. In the 1970s, data rates were routinely 100 kbps. Today we are pushing the limits of our capabilities to deliver 10 Mbps data streams from present-generation platforms. For next-generation*

platforms, we are anticipating demand for an order-of-magnitude increase in data capacity to include real-time high definition video [at 45 Mbps to 1.2 Gbps].

- *In the 1970s, there were no international standards for ranges. In the 1980s, Inter-Range Standards were developed by the Consultative Committee for Space Data Systems (CCSDS). Moving toward a common global range architecture for the future will require global spectrum agreement.*

The same ICTS presentation summarizes the U.S. perspective regarding worldwide access to adequate frequency spectrum for telemetry by noting:

- *Current spectrum barely supports today's aeronautical telemetry requirements and cannot support tomorrow's*
- *Additional spectrum somewhere below 30 GHz needed to accommodate:*
  -- Higher bit rates of next-generation flight test vehicles (space & aerospace)
  -- Newly emerging HRDV [high-resolution direct video] technology

Moving to Higher Frequency Bands

In light of this situation, according to a March 2001 article in the *ITEA Journal* by G. Derrick Hinton, Program Element Manager for the $140 million per year Central Test and Evaluation Investment Program (CTEIP) in the office of the Director, DoD Operational Test and Evaluation, there is a "pressing need for research in the technologies required to enable telemetry operations at frequencies higher than those in which they are currently conducted."[73] He points out that some frequency spectrum for range applications has recently been re-allocated while activities that use it have increased. Not only that, but over the past 30 years the combined effect of this decrease in available spectrum and the need for much higher data rates have established a "disturbing trend." He describes this trend as follows:

> *"In 1972, with only 258 MHz of available spectrum, approximately 1,501 simultaneous test missions could be conducted because each mission only required a 66 kbps data rate. Given the rate at which the demand for test data on the performance of weapons, sensors, platforms and command, control, communications, computers and intelligence (C4I) systems is increasing, the amount of data per mission is expected to reach as much as 78 Mbps.*
>
> *With current data link efficiencies of 2.6 Hz/bps, using the standard pulse code modulated-frequency modulation (PCM/FM) waveforms in Inter-Range Instrumentation Group (IRIG) 106 standard, a 78 Mbps data rate results in a total spectrum requirement of 203 MHz. . . . By the year 2015, the T&E community can expect to have only 205 MHz [and] only one mission could be supported at a time.*
>
> *The key to addressing and solving this problem will either be to develop techniques that can dramatically increase the data link capacity or move to less desirable, under-utilized frequency bands."*

Hinton's article notes that more efficient use of the currently allocated frequency spectrum for telemetry would help to address this problem to some extent, but he advocates moving to higher frequency spectrum as the only viable solution to supporting the rapidly increasing demands for higher data rates and bandwidth. He notes that the agenda for the 2006 World

Radiocommunication Conference (WRC) includes discussion of additional telemetry frequency allocation between 3 and 30 GHz, which includes the Ka band.

Since 1993, NASA's Advanced Communication Technology Satellite (ACTS) and Italsat have been operating Ka band transponders in orbit to support experiments intended to enable development of commercial Ka band satellites. According to the Ka-Band Utilization Conference website (http://www.iicgenova.it/kaconf/index.html):

> *"Both satellites have demonstrated the usefulness of Ka-Band through novel system approaches including digital communications, on demand rain compensation, hopping spot beams, on board switching, integrated services, and demand-assigned channels of varying bandwidth to suit user needs. The programs also developed flight and ground components as needed to stimulate the use of this new frequency band, and a wealth of information about Ka-Band propagation characteristics in Europe and the United States."*

The Ohio Consortium for Advanced Communications Technology (OCACT) took over the continued operation of ACTS after it completed its primary mission in May 2000. It is paying NASA for the opportunity to operate ACTS to educate students on satellite operations and technology and to support continued experiments relating to the use of Ka-band communication satellites.[74]

In the late 1990s, numerous commercial satellite projects were proposed to provide broadband services at higher frequencies between 3 and 30 GHz, including the Ka-band. According to the 1998 supplement to the 1997 "Ka Band Report" by DTT Consulting[75]:

> *"The Ka-band available for satellites is between 17.7 GHz and 21.2 GHz and 27.5 GHz and 31 GHz. The advantage of using Ka-band is that there is plenty of spectrum available (2.5-3.5 GHz, compared with around 1 GHz normally available for a Ku-band satellite).*
>
> *The Ka-band spectrum is also virtually unused, so there is room to accommodate frequency hungry two-way services.*
>
> *The use of multiple spot beams on Ka-band satellites will also ensure that this spectrum is used efficiently. Each Ka-band satellite will carry many spot beams (up to 48 or more), each covering small area of the world. This makes them very efficient in using spectrum."*

Using this available spectrum leads to advantages including larger bandwidth and higher data rates compared to transmissions at lower frequencies.

Technical Challenges Associated With Transmissions at Higher Frequencies

Several problems arise when transmitting electromagnetic energy at higher frequencies in the range of 3 to 30 MHz using current technologies. Some of these problems are highlighted below, along with some new technologies, approaches, and development efforts that could be pursued to address these problems in ways that would make the use of higher frequencies more feasible for telemetry.

For instance, atmospheric absorption increases with frequency (particularly above 10 GHz), and it varies with the absorption characteristics of atmospheric constituents including especially water vapor and oxygen. The graph in Figure G-1 shows how absorption varies with frequency in the millimeter wave portion of the electromagnetic spectrum, which includes the Ka-band and the region between 3 and 30 GHz that is on the agenda to be considered for telemetry uses at the WRC in 2006.

Attenuation from rainfall also increases rapidly with frequency, particularly above 10 GHz, and it reaches significant levels when even moderate rain is falling. As shown in Figure G-2, the Ka-band and the entire region of the frequency spectrum between 3 and 30 GHz are subject to substantial attenuation from rainfall.

Interestingly, these absorption and attenuation issues can be addressed by using spatial diversity (i.e., multiple platforms communicating along multiple paths) and operating at higher altitudes to avoid rain, clouds, and the need to transmit through most of the atmosphere - an approach that could be accomplished by using multiple interlinked mobile range platforms like UAVs or high-altitude airships, and satellites.

Transmissions Through Plasma

Another of the significant challenges in acquiring telemetry is to receive signals through the plasma that surrounds reentering spacecraft. The Plasma Wave Advanced Receiver (PARX) project at NASA Goddard Space Flight Center is a demonstration of ultra-low-power electronics technology to demonstrate a plasma wave receiver with one tenth the mass, volume, and power of current designs, enabling its use on small satellites and launch vehicles. It is also intended to include digital data compression with fast, onboard processing to reduce the output telemetry rate.

Above 10 GHz, atmospheric absorption increases and depends on the chemical makeup of the atmosphere.

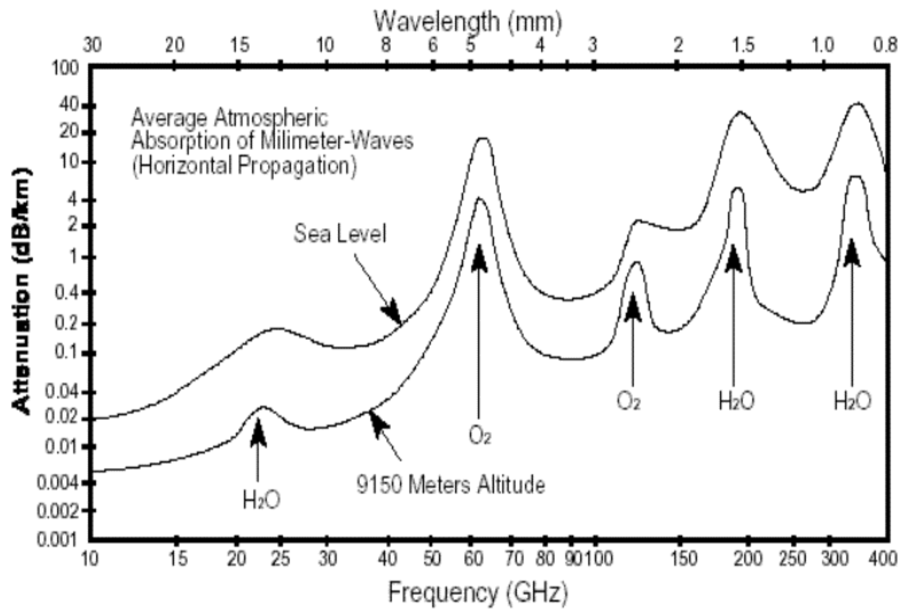

Figure G-1 Atmospheric Absorption of Millimeter Waves[76]

The intensity of precipitation affects the atmospheric attenuation of millimeter waves.

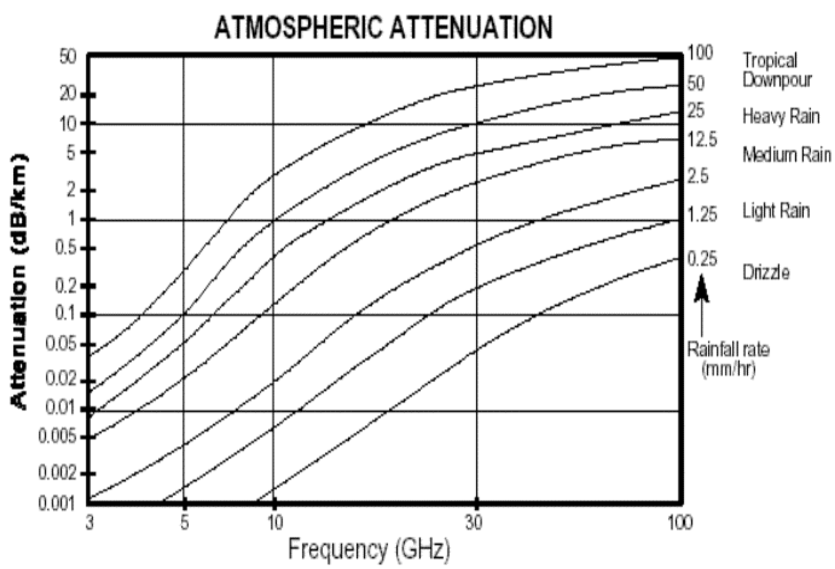

Figure G-2 Atmospheric Attenuation of Millimeter Waves Due to Rain[77]

High-Frequency Power Amplifiers with Wide Bandgap Semiconductors

In addition to the problems previously noted, it is also more difficult to design efficient power amplifiers that operate at higher frequencies. Lower efficiency leads to higher power requirements, which in turn result in increased heat that must be dissipated from telemetry systems aboard flight vehicles. Hinton's article notes that experimental prototype amplifiers operating at frequencies up to 30 GHz are under development, but only at the 1-watt power level. Telemetry applications on ranges will require power amplifiers with up to 100 watts of power to overcome the losses and inefficiencies associated with operating at higher frequencies.

To enable the development of such high-frequency power amplifiers, materials research and development work with wide bandgap semiconductors like gallium nitride (GaN) and silicon carbide (SiC) will be required. Such material research and development work with wide bandgap semiconductors is underway for a variety of other applications, including laser diodes and photodiodes[78], photonic detectors to detect and control automatic welding apparatus or detect fires, to fabricate optical semiconductor devices to operate at the blue and ultraviolet wavelengths, and (with SiC substrates and aluminum nitride insulators) to build chemical sensors with potential applications in automotive exhaust systems[79]. It may be possible to leverage this research being conducted by a variety of university researchers, but the Naval Research Laboratory is also actively pursuing wide bandgap semiconductor research for the express purpose of improving power amplifier designs for high-frequency applications[80].

> *"The Navy and the Department of Defense have increasing needs for electronic devices which operate at higher frequency, higher power, higher temperature and in harsh environments, for applications such as sensor components in jet engines or airborne microwave devices [e.g., power amplifiers for telemetry systems aboard flight vehicles]. GaN is an excellent candidate material for such applications, because it is chemically stable at high temperatures, has good thermal conductivity, a high breakdown field and a large electron saturation velocity. Consequently, the [Naval Research Lab] is putting a significant effort into advancing GaN device technology. . . .*
>
> *The Electronic Materials Branch has a solid record of contributions in wide bandgap semiconductor research, with work on silicon carbide, diamond and the nitrides. Currently the Branch plays a key role in the advancement of GaN and SiC technologies within the Division by addressing the essential issues of materials growth and impurity incorporation in both current and newly-emerging growth techniques.*

Already, some commercial products are available to operate in the Ka-band, with small transceivers (e.g., less than 1000 cubic inches) capable of operating at 100 watts. If commercial demand for Ka-band equipment grows, then more commercial products will likely be developed, making smaller, lighter, more powerful systems more readily available for operating at higher frequencies.

APPENDIX H – Laser and Free-Space Optics (FSO) Communications

To address the need for high data rate telemetry in the face of uncertain future frequency spectrum assignments, free space optical and other laser communications at unregulated optical wavelengths offer some potential advantages.

Free-Space Optics Communication Systems

Free-Space Optics (FSO) is a communication technology that can provide voice, video, or data links with capacity up to 2.5 Gbps using unregulated, line-of-sight, full duplex optical connections between transceivers (i.e., high-power optical sources, lenses, and processing equipment) through air or space.[81] FSO systems can be based on lasers of light emitting diodes (LEDs) and have been in use for more than 30 years. FSO technology can provide similar bandwidth to fiber optic connections, use similar optical transmitters and receivers, and can enable wavelength division multiplexing (WDM) approaches to enable transmissions at up to 10 Gbps between transceivers separated by air or space. However, several challenges must be addressed in designing and using FSO communication systems, including:[82]

- Motion of the transceivers: Precise alignment is necessary to maintain the line-of-sight connection between transceivers, and using a divergent beam and tracking devices can help, though this is probably the most challenging aspect associated with using FSO links on mobile platforms.

- Absorption: Atmospheric moisture attenuates (i.e., reduces the energy of) some wavelengths more than others so using appropriate frequencies, power, and redundant beam paths helps to ensure the reliability of the communication path.

- Scattering: Scattering can be caused by particles suspended in the atmosphere that are smaller than the wavelength of the FSO beam (Rayleigh), about the same size as the wavelength (Mie), or larger than the wavelength (nonselective). In each case, scattering can reduce the beam intensity, particularly over long distances.

- Physical obstructions: Today's FSO systems can reestablish communications after temporary blocks (e.g., birds flying through the beam), but again using a multibeam systems (spatial diversity) contributes to the reliability of the link.

- Scintillation: Temperature variations within the atmosphere lead to varying optical properties and fluctuations in FSO signal amplitude.

- Refractive turbulence: Refractive turbulence causes beam wander when turbulent eddies that are larger than the beam and beam spreading.

NASA's Jet Propulsion Lab has a staff of 15 people dedicated to optical communications and for 25 years has been exploring the use of FSO and laser communication systems for a variety of applications requiring connections between a variety of moving platforms, within and outside the atmosphere, including:[83]

- Deep space probes, to and from fixed ground stations on Earth, to "enable space missions to return 10 to 100 times more data with 1% of the antenna area of current state-of-the-art communications systems, while utilizing less mass and power"

- Satellites in GEO or LEO, to fixed or mobile ground stations on Earth, and between satellites in LEO and/or GEO

- Airborne platforms (e.g., UAVs), to fixed or mobile ground stations on Earth, and between airborne platforms

JPL's primary motivation in pursuing these FSO and laser communication links is to address future needs for data rates 10 to 100 times higher than those that are available today to enable transmissions from video, high-definition television (HDTV), multi- and hyper-spectral sensors, and synthetic aperture radar instruments. By addressing ways to improve the data rate so dramatically from deep space probes, NASA hopes to enable many other high data-rate applications as well and is participating in DoD's Transformational Communication program. In pursuing this research, JPL has built, tested, and demonstrated FSO and laser communication devices and systems to:

- Enable use aboard small spacecraft (e.g., 9 cubic-inch Small Communications Optical Package Experiment (SCOPE) and A Combined Lasercomm and Imager for Micro-spacecraft (ACLAIM))

- Enable high data-rate (i.e., 1 to 10 Gbps) transmissions to, from, and between satellites in LEO and/or GEO by exploring beam acquisition, tracking, and pointing technologies. JPL has demonstrated bidirectional optical links to and from GEO spacecraft and uplinks to spacecraft in deep space and has simulated LEO and GEO spacecraft interlinks capable of up to 7.5 Gbps data rates.

- Improve the efficiency of solid-state lasers (e.g., semiconductor optical amplifiers), flight-qualified lasers, and high update-rate focal plane detectors

- Monitor and characterize atmospheric attenuation using three 25-centimeter-diameter autonomous telescopes at the Table Mountain, CA, facility

- Track LEO spacecraft and experiment with laser communications using a 1-meter telescope system (Optical Communications Telescope Laboratory) dedicated to laser communication research

- Downlink data at up to 2.5 Gbps from a flying DC-8 aircraft and from a UAV to a ground station

Many of these technologies, approaches, and systems could be useful in enabling the transmission and receipt of range telemetry at much higher date rates from launch and flight test vehicles.

Laser Communication Systems

DoD's Transformational Communication System (TCS) is exploring the use of laser communication links, primarily between satellites, but such links could also potentially be used aboard launch and flight test vehicles as well. According to a January 2003 Aviation Week and Space Technology article, DoD's TCS is part of an overall push by the U.S. national security space sector to significantly upgrade its satellite communication infrastructure over the next ten years by developing about 20 large communication spacecraft worth $3-4 billion, which will in turn drive about $2 billion worth of space launch demand.[84] Alexis Livanos, Executive Vice President of Boeing Satellite Services, notes in the same article that advanced satellite communication technologies - including laser communications - will enable the transfer of data at up to 30 gigabytes per second - dozens of times faster than data can be transferred today - which will significantly enhance the utility of UAVs. Today, relaying the data stream from a single Global Hawk UAV requires three satellite links. Increased emphasis on UAVs and network-centric operations led DoD to initiate the TCS program with a $3 billion investment in FY 2003.

DoD has stated that the Transformational Communication Architecture (TCA) is intended to move away from today's situation characterized by circuit-based connections, complex terminals, and bandwidth constraints to a future vision that removes communications as a constraint to the user by providing Internet-like transport among fixed and mobile ground, air, and space assets. In short, the TCA aims to deliver:

- Rich, robust network connectivity
- Interoperability
- Assured availability and reliability
- Secure information transport

In developing plans to achieve this vision, the Transformational Communication Office (TCO) has identified a series of key technologies to enable development of the key elements of the architecture, including the MILSATCOM backbone for relay and access, terminals, and terrestrial infrastructure. The key technologies that will be required to enable its development include the following list with many parallels and overlaps with the list of technologies identified by the ARTWG Communication Architecture subgroup:

- Laser crosslinks between satellites
- Network standards and interfaces
- Multi-access lasercom
- Information assurance, networking testbed, and standards across all elements
- "Comm on the move" (COTM) antennas
- High-rate terrestrial networks

The same Aviation Week and Space Technology article notes that as this development work is underway, DoD, NASA, and the National Reconnaissance Office - all participants in the DoD Transformational Communication Office - are increasing their coordination on advanced satellite communication technologies, including laser communications. In December 2002, NASA launched the third and final upgraded second-generation TDRSS satellite (TDRSS-J) to complete its own $800 million upgrade program. NASA plans to continue to spend $700 to $800 million per year on data relay and satellite communications. The next TDRSS upgrade will be due in about 2012. NASA's participation in DoD's TCS program with laser communications as a key focus will lead NASA to a decision later in 2003 as to whether to equip its third-generation TDRSS satellites with laser communication capabilities. Either way, NASA plans that future TDRSS satellites will be equipped to relay data in radio frequencies.

In the mean time, the first U.S. military communication satellite to be equipped with laser links will likely be a later-model Wideband Gapfiller satellite. Boeing has a $600 million contract to build the first three satellites for launch starting in mid-2004, but these three will have X- and Ka-band communication payloads, but no lasers. The next three (4, 5, and 6 in line) are more likely to carry laser communication links to demonstrate the utility of high data-rate inter-satellite links, leading to more uses as part of the TCS in the future.[85]

The European Space Agency Advanced Relay and Technology Mission, or ARTEMIS, satellite has already demonstrated the use of laser communication links to and from satellites.[86] It was launched in July 2001, but (due to an upper-stage problem) it took 18 months using its ion propulsion system to reach geostationary orbit in January 2003. During this long trip to its operational orbit, ESA demonstrated that all of ARTEMIS' payloads (S-band, Ka-band, the optical data relay, and L-band mobile communication payload) were operating correctly. While ARTEMIS was in transit, its optical data transfer capability was used for the first time in November 2001 to receive SPOT-4 imagery data through a laser link and retransmit it to the optical ground station at Tenerife in the Canary Islands. According to ESA, between November 2001 and February 2003:

> *In total, 26 attempts were made to establish the optical link and all 26 were successful. The link was never lost before the preprogrammed point in time. Link quality was almost perfect: a bit error rate better than 1 in 10^9 was measured.*

Despite the successful recent completion of the 18-month, $21 million recovery effort, which has left ARTEMIS in its intended orbit where it could provide efficient data relay services for a number of Government and commercial Earth observing satellites, the fact that ESA has invested a total of $970 million in ARTEMIS - which still has an estimated 10-year lifespan left - and the numerous successful demonstrations of laser communication capabilities in and from space, ESA is now ready to shut down or sell ARTEMIS unless European member governments appropriate additional funding for its continued operations at about $8 million per year.[87]

APPENDIX I – Alternative Approaches To Using Frequency Spectrum

For more than a decade, Bell Labs has been addressing ways to use reflections and scattering of signals, or multipath interference, to improve reception and significantly increase data rates using a given amount of frequency spectrum under a program called Blast. Blast uses array antennas to divide and transmit data in multiple streams on the same frequency, so the signals are distributed in space as well as time. This approach enables volume-to-volume exchanges instead of point-to-point exchanges that are more typical of communication systems. Blast has been demonstrated to increase the data throughput of third generation (3G) wireless networks by a factor of eight, or up to 19.2 Mbps versus the 2.5 Mbps they are designed to handle in point-to-point applications.[88] The key to this system is the use of multiple, physically separated antennas to transmit signals and processing software to reassemble the data streams. Adding more transmitting antennas adds more capacity to the system, and reflections and scattering add even more capacity by acting as additional transmitters in the network. The speed of the data processing to reassemble the signals is the factor that limits the capacity this approach can add to a system. Lucent Technologies is building wireless network base stations that can be adapted to use Blast, but some in industry anticipate that commercial companies may wait for the military to develop the technology and pioneer its use.

Another way to increase data rates using a given amount of frequency spectrum is to continuously monitor its use and coordinate jumps to other frequencies that are not in use at the time. DARPA is pursuing this approach to treating spectrum use as a dynamic system through its five-year Next Generation (XG) communications program[89], which began by measuring current spectrum usage in the U.S. and found that at any given moment, only two percent of the assigned spectrum is actually being used. This finding led DARPA to explore whether the spectrum that is not in continuous use could be exploited without interference. To exploit this unused spectrum, DARPA is pursuing four technologies:

- Low-power, compact spectrum sensing capabilities that can be embedded into XG communication systems

- Characterizing spectrum use to develop an understanding as to whether or how various signals could coexist in a dynamic environment without interfering with each other

- Reacting to other spectrum users to enable the selection and coordination of frequencies and bandwidth

- Adapting to changes in spectrum use in the vicinity of an XG communication system (e.g., commencement of radar scanning in the area, new mobile devices entering the area, or the XG device moving to a new area where other transmitters are already operating) by developing, coordinating, and disseminating new spectrum use plans among XG network devices

DARPA envisions that XG network operations will include autonomously detecting, coordinating, and managing local spectrum use through common protocols. This capability is particularly important for military systems that must operate worldwide, where frequency spectrum assignments and usage vary from place to place because they are regulated by national or regional authorities. Similarly, this type of capability could be extremely useful for range applications that span significant areas around the globe.

Another alternative approach to the use of frequency spectrum is ultra-wideband (UWB) communication, with roots in time-domain electromagnetic research as far back as 1962.[90] UWB capabilities hinge on subnanosecond (baseband) pulse generation, wideband radiating antennas, and sensitive, short-pulse receivers. In addition to low probability of intercept and detection (LPI/LPD) communications (with systems fielded since the late 1980s), UWB applications include radar, collision avoidance, positioning systems, liquid level sensing, and altimetry.

As with any radio frequency wireless technology, UWB applications require tradeoffs between signal-to-noise ratio versus bandwidth, range versus peak and average power levels, etc., but UWB advocates note that it can enable:[91]

- High data rate performance in multiuser communication networks using packet burst and time division multiple access (TDMA) protocols
- Precision distance and/or positioning measurement in radar applications
- Immunity to multipath interference
- High-speed, mobile wireless communication applications
- Low energy densities (i.e., transmitted watts of power per unit Hertz of bandwidth) for low probability of detection (LPD) and intercept (LPI)
- Low system complexity and cost, nearly "all-digital," minimal radio frequency or microwave electronics, and adaptable to multiple frequencies

In June 2002, the Defense Advanced Research Projects Agency (DARPA) solicited research proposals on innovative and revolutionary approaches to UWB array antennas “to enhance the performance of, and enable entirely new capabilities and architectures for tactical and strategic radio frequency systems by expanding the instantaneous bandwidth available in system front ends. . . . The program goal is to demonstrate multibeam, multi-octave operation of a small array antenna(s).”[92] This research (which DARPA planned to fund at $50 million over four years) addresses structures for array antennas, low-noise amplifiers, beam-forming approaches for 10-100 beams.

NASA Johnson Space Center is also pursuing UWB data systems to enable two-way astronaut to spacecraft wireless telemetry and communication links. NASA notes that within the last few years, low-cost ultra-high precision oscillators have become available, making it possible to build UWB communication systems without a baseband frequency.

In March 2003, DARPA issued a Broad Agency Announcement to solicit ideas for research into Networking in Extreme Environments (NETEX)[93], to create UWB sensor and communication systems and support their integration into a wireless networking technology that enables robust connectivity in harsh military environments. This announcement follows on to the initial NETEX UWB study in FY 2002-2003 to understand interference between UWB and existing narrow band spectrum users and how to minimize it. The next five-year phase of the NETEX program will (1) develop UWB communication systems that can coexist with legacy systems and intentional jammers, (2) develop algorithms, protocols, and distributed control for robust, scalable ad hoc networking, and (3) conduct experiments to demonstrate the military utility of UWB sensor and communications networks.

APPENDIX J – Display Technologies

DARPA's Information Exploitation Office (IXO) is pursuing the Rapid Knowledge Formation (RKF) project to "enable distributed teams of subject matter experts (SMEs) to author knowledge bases directly and easily without knowledge engineers serving as intermediaries. This technology will permit scientific, technical, and military experts to encode massive amounts of knowledge into reusable knowledge bases for applications in many different problem-solving situations."[94]

An excellent and comprehensive review of current and coming video display technologies can be found at http://www.epanorama.net/links/videodisplay.html, including discussions of analog and digital display systems like CRT, LCD, and plasma screens, as well as various projection technologies, systems, and devices.

Research into 3-D display technologies has been pursued at Stanford University for at least two decades. According to a 1996 Stanford news release:[95]

> *Over the years, researchers have come up with a number of different ways to produce three-dimensional images. Most of these rely on various tricks to fool the eye into converting two-dimensional images into three-dimensional scenes. They range from the paper glasses with red and blue lenses used to view 3-D movies to the virtual reality display systems that create the illusion of depth by employing two small televisions to deliver slightly different perspectives of the same view.*
>
> *Another basic approach has been to use holography, which stores three-dimensional information in invisible patterns on a special film. When this film is illuminated by laser light, three-dimensional images appear to a viewer looking through the film.*

Stanford researchers produced a true 3-D display using fluorescent glass in 1996, but the objects it displays are transparent, not opaque, and it takes 500 times as much data to display a 3-D object as it does to draw an object for a 2-D display.

Actuality Systems has developed the Perspecta™ 3D System, a spherical Lexan™ display with 100 million addressable pixels inside which can display 3-D spatial representations of various types of user data. The company has found markets as diverse as medical imaging, air traffic control, game development, molecular modeling for drug research, and visualization for security checks.[96]

There are also immersive environments for 3-D visualization and display in use for various Government and commercial applications. For instance, the Army Tank and Automotive Research, Development and Engineering Center (TARDEC) uses such capabilities to aid in the design of future army vehicles. For example, Division ProductView (immersive) and Windchill ProductView (desktop and web-enabled) visualization software and display settings by Fakespace Systems combine to form:[97]

- CAVE (CAVE automatic virtual environment) - an enclosed room for up to six people, using rear-projected screens on the floor, ceiling, and walls, costing about $400,000

- RAVE II (reconfigurable automatic virtual environment) - a set of hinged 8-foot by 10-foot screens that can be configured form an enclosed space, a large wall, or other shapes

APPENDIX K – Data Recording, Storage, Retrieval, and Archiving

Companies like Advanced Digital Information Corporation (ADIC) offer commercial off-the-shelf, expandable, modular, network-accessible, automated mixed media library systems that can store and enable access to more than a dozen types of storage media and technologies.[98] The Sun StorEdge L700 Tape Library is another example of a commercial off the shelf scalable, expandable archive storage system.[99]

DARPA's Information Processing Technology Office (IPTO) is pursuing more than a dozen projects under the heading Data Intensive Systems (DIS), with the shared goal of exploring new memory architectures concepts, techniques, and implementations that reduce data bandwidth and data access latency limitations.

DARPA's Information Exploitation Office (IXO) Model-Based Integration of Embedded Software (MoBIES) program is developing interoperable tools to design and test complex computer-based systems such as avionics, weapons, and communications systems. These tools are intended to simplify the design of complex embedded systems by focusing on ways to automate controller design and systems integration.[100]

Blue laser optical disk storage technology refers to a next-generation industry standard (i.e., 12-cm diameter Blu-ray disk with a capacity of up to 27 Gbytes) that has been jointly proposed by nine of the world's largest electronics companies for recording up to two-hours of high-definition television (HDTV) video.[101] Six of the ten companies that developed the digital versatile disk (DVD) format participated in developing the Blu-ray standard, but four did not - so there could be a format battle on the horizon, as occurred during the development of previous standards. Blue lasers (405-nm wavelength) can focus on a smaller area than the red lasers (650-nm wavelength) used for current compact disk (CD) and DVD systems, enabling more data to be stored on a smaller area on the disk. Companies are working to develop less expensive blue laser diodes so production prices will be affordable for consumer products.

DARPA/MTO and Call/Recall Inc. are pursuing Fast Readout Optical Storage Technology (FROST) to "combine the density and removability advantages of multilayer optical storage media with VLSI [very large scale integration] Photonic techniques to develop parallel optical readout systems enabling orders of magnitude improvement in capacity and data transfer rate. The end-goal of the program is to develop a bit-oriented volumetric storage media with a parallel readout head to demonstrate a high-capacity (50 GByte), high-throughput (2 Gbps data rate), removable optical memory disk system."[102] Technology approaches include photochromic polymers, vertical cavity semiconductor diode laser arrays (VCSEL), optical illumination and 3-D imaging systems, micro-mechanical optical actuator chips, high-performance detector arrays, parallel data channel electronics, and micro-optical packaging techniques.

As part of its UltraScale Computing effort in 1997, DARPA sought proposals Hybrid Storage among other enabling component technologies to develop mechanisms for data storage and retrieval from organic, cellular, or tissue-based memory subsystems and a demonstration of technology that enables greater than one bit per cubic nanometer data storage capability.[103]

Researchers at IBM are pursuing development of Patterned Magnetic Media to improve the data density of magnetic disks (currently 6 Gbit per square inch, but doubling every 1.5 years), which currently use several hundred grains of magnetic media to store a bit of data, beyond the limit that is achievable by continuing to reduce grain size. When the grains get sufficiently small, their magnetic properties become unstable when their temperature varies. One approach is to try to use a single grain to store a bit, which would improve data density by a factor of a few hundred. IBM is investigating two novel approaches to patterned media using thin polymer films: stamping and ion beam patterning.[104] The same IBM lab is also researching Antiferromagnetically Coupled (AFC) Media to develop magnetic storage media that is less sensitive to losses induced from reading the data.[105]

APPENDIX L – Antenna Technologies

In addition to advanced signal processing and data compression techniques, another approach to improving the ability of space launch and test ranges to use higher frequencies for telemetry would be to work toward improving antenna gain. Antenna gain is directly proportional to aperture size, while antenna patterns and sensitivity to various frequencies depend on the antenna's configuration and proximity to other conductive materials like metallic flight vehicle structures. Research to improve advanced dielectric materials and development work to improve antenna configurations could lead to the development of small, conformal antennas that would be suitable for use on flight vehicles. For instance, piezoelectric actuators could be used to change the shape of the antenna to improve its gain, pattern, and sensitivity to a range of frequencies.

DARPA is pursuing several different approaches to antenna technology, including the Innovative Space-Based Radar Antenna Technology (ISAT) by DARPA's Special Projects Office (SPO). The objective of the IST program is to assess lightweight, compressible materials and rigidized inflatable structures and to produce feasible and affordable candidate designs of extremely large space-based radar antennas capable of performing ground moving target indications (GMTI) from space.[106]

Another example is the Steered Agile Beams (STAB) program by DARPA's Microsystems Technology Office (MTO). The STAB program is developing small, lightweight laser beam scanning technologies for the replacement of large, heavy gimbaled mirror systems. STAB technologies are expected to enable tactical laser communications. New solid state/micro-component technologies such as optical micro-electromechanical systems (MEMs), patterned liquid crystals, diffractive microoptics and photonic crystals will be used to build small, ultra-light, rapidly steered laser beam subsystems.[107]

Similarly, DARPA's Reconfigurable Aperture Program (RECAP) by its Special Projects Office (SPO) is pursuing revolutionary antenna technology for future military needs in high capacity communication and sensors. Several advanced technologies are being integrated into demonstrations that will show substantial new capabilities such as multibeam arrays for communication and multiband radar links that electronically reconfigure to provide hemispherical coverage. This technology is expected to allow the number of antennas on aircraft and ships to be reduced by a factor of 5 – 10. Thin, lightweight, conformal aperture designs will facilitate integration into mobile and airborne platforms.[108]

DARPA's Advanced Technology Office (ATO) is also pursuing antenna and communication technologies to assist with interoperability. For instance, the Airborne Communications Node (ACN) by DARPA/ATO was one of the first programs it had in its portfolio when it was established in 1999. The challenge was to enable different systems to communicate with one another. ACN is to function as a kind of "switch node in the sky" to connect different communication signals onto the same line. (By its nature, such a system could also be useful for SIGINT, electronic warfare, and information operations.)[109]

The DARPA Defense Sciences Office (DSO) is pursuing Frequency Agile Materials for Electronics (FAME) to electronically steer antennas and to have frequency and phase-agile radio frequency and microwave components. The FAME program seeks to develop tunable components with very low losses. Today, the penalty in signal-to-noise was too high for many of these tunable devices to be practical, but several new electric and magnetic field tunable materials have been discovered or developed under this program. The FAME program plans to demonstrate several prototype components, including a tunable satellite communication patch antenna that conforms to the vehicle surface; an electronically steered 2-D phased array for a missile seeker radar; and several new phase shifter designs with better performance at millimeter wave frequencies than the current state-of-the art, at much lower cost.[110]

Multimode and Phased Array Antennas

Multimode antennas promise significant advantages in cost, weight, and volume for sensors, receivers, and transmitters - factors that are particularly important for range equipment that is to be used on space-based and mobile platforms providing range tracking and surveillance functions, as well as telemetry receiving and communication relay functions.

NASA Glenn Research Center is pursuing the development of prototype multibeam phased array antennas through a project investigating alternative control schemes to reduce cost and weight while improving performance. Such a capability could enable on-orbit or mobile range assets to be reconfigured to transmit or receive in multiple frequency bands, adding capability, flexibility and adaptability, while addressing the uncertainty associated with future assignments or access to particular portions of the frequency spectrum.

NASA Glenn Research Center is also investigating film-based ferroelectric tunable microwave circuits to enable development of an entirely new type of scanning phased array antenna - the ferroelectric reflectarray antenna (FRA, US patent # 6,081,235). The FRA promises to offer the high efficiency and low cost of a gimbaled parabolic reflector and the vibration-free beam steering of a direct radiating phased array.

NASA Langley Research Center is developing optical phased arrays using liquid crystals on silicon substrates to enable nonmechanical optical beamsteering, eliminating the need for heavy mechanical components, and enabling compact, low-power, light-weight optical phased arrays with better control with greater flexibility in steering.

DARPA's Microsystems Technology Office (MTO) is pursuing research into Vertically Interconnected Sensor Arrays (VISA) to develop three-dimensional readout architectures and circuits for imaging focal plane staring arrays for high resolution, ultra-wide dynamic range (> 20 bits), multispectral, and very fast imaging capabilities.[111] Such technology would enable imaging dim targets in the presence of background noise, countering laser jamming, and defeating camouflage, concealment, and deception. The VISA program will address five main technologies for sensor arrays:

- Process technology for dense focal plane interconnections
- Novel pixel readout circuits
- 3-D integrated focal plane technology demonstrations
- 3-D focal plane architectures and readout technologies
- 3-D focal plane array applications study

APPENDIX M – Network Approaches to Distributing Voice, Video, Data

The Internet is the most obvious example of a network that is capable of distributing voice, video, and data to multiple locations.

In considering ways to take advantage of current network system capabilities, Cisco, Agilent, Nortel, and others offer commercial off-the-shelf multiprotocol label switching (MPLS) virtual private network (VPN) components and systems to transfer secure voice, video, and data at guarantees levels of quality of service (QoS). Speeds of these connections are available between 64 kbps and 155 Mbps.

For example, the Air Force Flight Test Center (AFFTC) at Edwards Air Force Base, California, and the FAA are working together to share the new $4.5 million East Data Acquisition Transmission System (EDATS) network, which was tested for the first time on November 22, 2002, with data from an F/A-22 test flight.[112] EDATS connects real-time data from Edwards (through a series of 28 microwave relay sites that are also used to pass FAA radar and air traffic control data) to the control center at White Sands Missile Range, NM. It is the newest addition to an overall range network that allows the real-time exchange of telemetry data among Vandenberg Air Force Base, the Naval Air Warfare Center Weapons Division at China Lake, and Point Mugu Naval Air Station, all also in California. The cooperative arrangement between the Air Forcer and the FAA allocates one third of the bandwidth on the system for use by the FAA, one third for the F/A-22, and the final third for other programs. Plans call for extending the network connection to Eglin AFB, FL as well, leading toward a single nationwide range network.

Several technical approaches and projects are being pursued to improve the ability of the Internet to perform these distribution functions on future space launch and test ranges.

For instance, the primary goal of the DARPA Next-Generation Internet (NGI) program is to develop networking and communications technologies to enable networks to scale dramatically in size, speed, and reach, focusing particularly on the capability to robustly accommodate extreme ranges of user demand.[113] The SuperNet Testbed enables researchers in both networking and applications arenas to experiment and field-deploy prototype tools, systems, and applications.

DARPA's Microsystems Technology Office (MTO) is pursuing Chip-Scale Wavelength Division Multiplexing (CS-WDM) for use in networks on military platforms. CS-WDM is intended to demonstrate ways to make WDM networks and components smaller, less temperature-sensitive, more reconfigurable, fault tolerant, and able to address both digital and analog data transmission requirements of military weapons systems and sensor networks (i.e., up to 32 channels at 1.5 Gbps each).[114]

To further add to the flexibility of such voice, video, and data distribution capabilities, DARPA's Advanced Technology Office (ATO) is exploring technologies to enable high data rate communications using mobile free space optics systems through its Tera Hertz Operational Reachback (THOR) program. In addition, DARPA's Information Processing Technology Office (IPTO) is pursuing more than a dozen projects under the heading Data Intensive Systems (DIS), with the shared goal of exploring new memory architectures concepts, techniques, and implementations that reduce data bandwidth and data access latency limitations. Some approaches include embedding logic or processors within the data stream or memory devices to speed processing time, adaptive cache memory to manage the placement of data within memory devices for rapid retrieval, and algorithms to take advantage of these new architectures and capabilities.[115]

Telemetry Networks

The Telemetry Group of the Range Commanders Council Inter-Range Instrumentation Group (IRIG) has recently developed an entirely new set of telemetry standards to allow ranges to implement network protocols and approaches like those used in transferring information on the Internet. This is another example of an approach to leverage commercial developments to make more efficient use of frequency spectrum. The February 2001 update to the IRIG-106-01, Part 1, Telemetry Standards, says[116]:

> *"The Telemetry Standards have taken on a new look effective with this release. The IRIG-106 is now published in two parts. Part I contains the more familiar information and standards that have been evolved over the years. Part II is a totally new entity. This new part is devoted to the standards associated with the present technological evolution / revolution in the telemetry networks area."*

The May 2001 IRIG-106-01, Part II, Telemetry Standards, explains how space launch and test ranges can take an evolutionary approach to implementing Telemetry Networks as commercial technologies continue to mature to the point where they can reliably be incorporated into the approaches used by the ranges.[117]

> *The concept of Telemetry (TM) Networks is currently evolutionary. Initial releases of this part of the standard, while incomplete, reflect those areas of the technology mature enough to define methods, techniques, and/or specifications needed to ensure interoperability among and across the ranges. The Range Commanders Council (RCC) Telemetry Group (TG) plan is to systematically expand the standards and information in this part to the point users are able to totally implement a telemetry network from the acquisition of data through the transmission and/or recording process.*
>
> *Rapidly changing technology and acquisition reform have led the Department of Defense to rely more heavily on commercial off-the-shelf (COTS) hardware and software. Consequently, existing and near horizon commercial communications standards are implemented or tailored to the maximum extent possible.*
>
> *The TM Networks standards addressed here will describe systems that use packetized data, protocols, and architectures similar to traditional computer networks.*
>
> *This Range Commanders Council standard defines the recommended methodology for packet telemetry (wireless) radio frequency transmissions using the Consultative Committee for Space Data Systems (CCSDS) data multiplex format. 'The CCSDS is an international organization of space agencies interested in mutually developing standard data handling techniques to support space research conducted exclusively for peaceful purposes.' (Quoted from their web site: http://www.ccsds.org.)*

The concept of packetized digital communications is not new and has been in use for a number of years. The protocols used in computer networks, such as TCP/IP, are packet systems. Its utilization in the RF arena for aircraft and missile telemetry and for satellite communications and telemetry purposes is a more recent application of the concept.

The current approach being pursued by the ranges, through this standard, is to rely on the data multiplex format developed, recommended, and advocated by the Consultative Committee for Space Data Systems (CCSDS), an international body. The purpose of the IRIG 106-01 Telemetry Standards is stated as follows:

"This standard for RCC recommended packet telemetry references the CCSDS Recommendation and places the 'tailored' requirements which are unique to the RCC telemetry applications within the body of IRIG Standard 106."

APPENDIX N – Most Pressing Mission Support Functions

Technical Approaches To Support Missile Intercept End-Game Analysis

One of the most persistent, stressing T&E requirements on the space launch and test ranges is driven by missile defense testing: that of vector miss determination. In fact, a 1988 study conducted by ITT at Vandenberg Air Force Base inventoried the Air Force ranges to determine their command, control, and communications (C3) requirements. The end-game vector miss determination associated with missile defense testing was found to be the most stressing requirement in terms of accuracy, update rate, and attitude requirements.[118] According to an input regarding this point, received from the 30th Space Wing at Vandenberg AFB on August 5, 2002:

> *"The required accuracy for this miss determination [between target and interceptor vehicles] is on the order of several centimeters. The expert opinion at this point is that the requirement likely can be met only with very tightly coupled GPS/IMU instrumentation on-board both vehicles, providing data for post mission processing. The complexity and cost of using GPS receivers in such an instrumentation package appear formidable. The technical challenge for a receiver is to maintain realtime phaselock tracking during abrupt, impulsive-type maneuvers. The task is greatly simplified by using translators, wherein high fidelity phaselock tracking is accomplished in post mission playback. The feasibility of the translator approach has been verified; that of the receiver approach has not. Alternative non-GPS approaches, proposed to this point, have all suffered fatal major deficiencies."*

Even in the near-term, the Missile Defense Agency's missile intercept testing requires the ability to address the end-game. Adequate analysis on the lethality of such missile intercepts requires precise knowledge of the trajectories of the interceptor and the target, including the attitude of each. For most flight test scenarios and launch operations, tracking data at 10 to 20 samples per second provides adequate accuracy. In contrast, the accurate determination of miss distances in missile intercept test scenarios requires at least 1,000 samples per second. While the feasibility of an approach using GPS receivers in this type of scenario has not been verified, Stanford Research Institute (SRI) has developed and proposed approaches and techniques that could address this scenario using GPS receivers.

One example is a training system SRI developed for the Army National Guard using two GPS receivers at one-meter separation strapped to a tank barrel. This system uses interferometry techniques to derive the precise barrel attitude (and projectile vector). This system, called DFIRST, has been very successful and many units have been fielded. SRI also proposed a GPS vector scoring system called Missile End Game System (MEGS) for air-to-air missile intercepts. It would use the same technique on the missile and target, but it has not been developed or fielded.

Another option demonstrated some years ago was called Photo Data Analysis System (PDAS). It used the photographic images of the encounter and scale models to produce accurate measurements associated with the entire end-game scenario.

Proposed Development Steps

- **Explore GPS Receiver Interferometry Techniques**. Given the advantages of GPS receivers over translators and current plans to rely more and more on GPS receivers for range tracking data in the future, it may be worthwhile to propose and pursue a technology demonstration to explore the potential applicability and value of interferometry techniques to derive precise missile intercept end-game data, as has been proposed by SRI.
- **Explore a Modernized Photo Data Analysis Approach**. It may also be worthwhile to propose and pursue a technology demonstration to illustrate the advantages possible by using a modernized photo data analysis approach using modern shuttered video capabilities aboard appropriately positioned airborne or spaceborne platforms to take the pictures of missile intercept end-game scenarios. Such an approach could be demonstrated in conjunction with other demonstrations using mobile assets like UAVs or high-altitude, long-duration airships carrying appropriate range instrumentation and optical systems.

The 1998 RCC Radar Roadmap estimated that the cost of five imaging radars (four active plus one spare) and associated equipment to be $15M or less. The Missile Defense Agency (MDA) is the most likely agency to require such range support. The 1998 RCC Radar Roadmap noted that an existing tracking radar could be modified to demonstrate a wideband radar imaging capability and that "one company claims to be able to modify an existing single-object tracker to produce an imaging radar for about $4M each, assuming the radar is fully serviceable before modification. Another company is working on adding wide bandwidth to the multiple object trackers."

- The DoD range community may find it worthwhile to seek synergy with MDA to fund the development and testing of imaging radars as a means of improving range capabilities.

- Consistent with the RCC Radar Roadmap, each range should buy imaging radars as needed. Such capabilities could first be demonstrated using deployable platforms (e.g., trailers) and later be included on mobile platforms (e.g., dirigibles or UAVs).

Incorporating Information Assurance Principles

The operation of space launch and test ranges are among the important DoD functions that face threats from hackers and other unauthorized users who regularly attempt to modify, steal, inappropriately disclose, and destroy sensitive data. In March 2000, the Deputy Secretary of Defense issued a guidance and policy memorandum recognizing the pivotal role of global networking in DoD activities and requiring the use of IA safeguards and operational procedures for all of DoD. The space launch and test ranges are relying increasingly on interconnected information systems, which results in sharing of security risks among all interconnected organizations. In this environment, an adversary need only find and penetrate a single, poorly protected system and then use access to that system to penetrate other interconnected systems. Consequently, coordination of IA efforts across DoD and all range users is important to maintain adequate security throughout its systems and networks. In light of this situation, as the DoD and

NASA range community considers the design of range systems and technology demonstrations, the following specific near-term considerations should be applied:

- DoD could find it worthwhile to conduct a threat simulation exercise to develop a clearer understanding as to the vulnerabilities of its current space launch and test range architecture and compare these results to the vulnerabilities that would be present in a space-centric range architecture supplemented by mobile range assets.

- Assess the security and risks associated with the information systems used to transfer, process, and display range data, as required by the Federal Information Security Reform Act (FISRA). Several organizations are available to assist Government organizations with information assurance efforts. For example, the National Information Assurance Partnership (NIAP), led by NIST, provides services including security testing, standards development, IA research, tools, and techniques. The Information Assurance Technology Framework Forum (IATFF) is another resource that addresses both Homeland Security and Critical Infrastructure Protection.

- Contact the CERT® Coordination Center (CERT/CC), a center of security expertise, at the Software Engineering Institute, a federally funded research and development center operated by Carnegie Mellon University and use its Operationally Critical Threat, Asset, and Vulnerability Evaluation (OCTAVE) - a comprehensive, repeatable technique - to identify risks in networked systems over time.

- In considering system-level design concepts for improved range capabilities, DoD and NASA should actively ensure that the following IA principles are addressed in a balanced manner:

  1. <u>Confidentiality</u> - assurance that information is not disclosed to unauthorized persons, processes, or devices

  2. <u>Authentication</u> - security measure designed to establish the validity of a transmission, message, or originator, or as a means of verifying an individual's authorization to receive specific categories of information

  3. <u>Data Integrity</u> - condition existing when data is unchanged from its source and has not been accidentally or maliciously modified, altered, or destroyed

  4. <u>Availability</u> - timely reliable access to data and information services for authorized users

  5. <u>Nonrepudiation</u> - assurance the sender of data is provided with proof of delivery and the recipient is provided with proof of the sender's identity, so neither can later deny having processed the data

- Adopt a "Defense in Depth" strategy in range data and information systems, including a barrier to outside networks, internal digital perimeters and a protected workstation/platform environment with real-time network surveillance, intrusion detection, event correlation, and reaction to computer network attacks to prevent catastrophic failures [National Security Telecommunications and Information Systems Security Instruction (NSTISSI) No. 4009, January 1999 (Revision 1)]

Addressing Frequency Spectrum Issues

Various advanced signal processing techniques and approaches could be pursued to make more efficient use of frequency spectrum and address the absorption and attenuation problems associated with the use of higher frequencies for telemetry transmissions. Here are several near-term steps that could be pursued:

- The DoD and NASA range communities should consider monitoring, coordinating among, and leveraging various ongoing Government and commercial efforts focused on signal processing, to add particular emphasis to the pursuit of techniques that could be used to improve the quality and efficiency of low signal-to-noise transmissions at higher frequencies.

- Specifically, DoD and NASA may consider it worthwhile to sponsor or coordinate research or technology demonstrations on active ranges, to explore the potential applicability of:

  1. Advanced equalization techniques to lower bit error rates

  2. Advanced modulation techniques to make more efficient use of frequency spectrum

  3. Advanced error correction techniques (e.g., Turbo codes) to make more efficient use of higher-frequency spectrum for telemetry

- The DoD and NASA space launch and test range communities may consider it worthwhile to establish a more interactive and cooperative role with the UAV Battlelab at Eglin Air Force Base, Florida, to explore whether the specific data compression techniques it is developing for UAVs could be applied to make more efficient use of the frequency spectrum used by space launch and test ranges, particularly for high-data-rate telemetry.

- Seek interaction and a cooperative working relationship with DISA's Joint Interoperability Test Command (JITC) at Fort Huachuca, Arizona, as a means of identifying potential range datalink improvements based on JITC's experience testing operational datalink capabilities.

- DoD or NASA may wish to consider the potential value of participating in, or expanding the Naval Research Lab's materials research relating to wide bandgap semiconductors to enable the development of power amplifiers suitable for use at higher frequencies for range applications.

- In devising and constructing range technology or capability demonstrations involving telemetry and commanding from space-based and/or mobile platforms, consider incorporating packetized data, protocols, and architectures similar to traditional computer networks.

APPENDIX O – Abbreviations and Acronyms

2-D	two dimensional
3-D	three-dimensional
3-G	third generation wireless technology
4-D	four dimensional (i.e., three spatial dimensions plus time)
ABFM	Airborne Field Mill
ACLAIM	A Combined Lasercomm and Imager for Micro-Spacecraft
ACN	Airborne Control Node, Airborne Communication Node
ACTD	advanced concept technology demonstration
ACTS	Advanced Communication Technology Satellite
ADIC	Advanced Digital Information Corporation
ADS	Advanced Distributed Simulation, Automatic Dependent Surveillance
AEHF	Advanced Extremely High Frequency
AF	Air Force
AFB	Air Force Base
AFC	Antiferromagnetically Coupled
AFFTC	Air Force Flight Test Center
AFRL	Air Force Research Lab
AMTI	Air Moving Target Identification
AMU	Applied Meteorology Unit
AOA	Analysis of Alternatives
AR	Automated Reasoning
ARIA	Advanced Range Instrumentation Aircraft
ARMS	Adaptive and Reflective Middleware Systems
ARTEMIS	Advanced Relay and Technology Mission
ARTWG	Advanced Range Technologies Working Group
ASD(C3I)	Assistant Secretary of Defense for Command, Control, Communications and Intelligence
ASTWG	Advanced Spaceport Technologies Working Group
AT&T	Acquisition, Technology, and Logistics
ATO	Advanced Technology Office
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
AWCWD	Naval Air Warfare Center Weapons Division
AWS	Advanced Wideband Satellite, Advanced Wideband System
BER	bit error rate
BGP	Border Gateway Protocol
BMC3	Battle Management Command, Control, and Communications
BMDS	Ballistic Missile Defense Systems
BMRST	Ballistic Missile Range Safety Technology
C2	command and control
C3	command, control, and communications
C4I	Command, Control, Communications, Computers, and Intelligence
CAVE	Cave Automatic Virtual Environment
CCAFS	Cape Canaveral Air Force Station
CCSDS	Consultative Committee for Space Data Systems
CCSDS	Consultative Committee for Space Data Systems

CCT	Command and Control Technologies Corporation
CME	Corona Mass Ejection
CNS	Communication Navigation and Surveillance
COA	course of action
COLA	collision avoidance
CONOPS	concept of operations
COTM	comm. on the move
COTS	commercial off the- shelf
CPFSK	Continuous Phase Frequency Shift Keying
CSIP	California Space Infrastructure Program
CS-WDM	Chip-Scale Wavelength Division Multiplexing
CTEIP	Central Test and Evaluation Investment Program
D&A	deconfliction and allocation
DAE	Digital Antenna Electronics
DARPA	Defense Advanced Research Projects Agency
DDR&E	DoD Director of Defense Research and Engineering
DFRC	Dryden Flight Research Center
DGPS	Differential Global Positioning System
DIAL	Differential Absorption LIDAR
DIFSERV	differential services
DIS	Distributed Interactive Simulation, Data Intensive System
DISA	Defense Information System Agency
DLT	desired lead time, Data Link Transceiver
DOC	Department of Commerce
DoD	Department of Defense
DRE	distributed, real-time, and embedded
DSO	Defense Sciences Office
DST	Decision Support Tools
DVD	digital versatile disk
DWDM	dense wavelength division multiplexing
EDATS	East Data Acquisition Transmission System
EELV	Evolved Expendable Launch Vehicle
EFTS	enhanced flight termination study
EIRP	Effective Isotropic Radiated Power
ELV	expendable launch vehicle
EO	electro-optical
EOM	end of mission
ER	Eastern Range
ERAST	Environmental Research Aircraft and Sensor Technology
ERDAS	Eastern Range Dispersion Assessment System
ES	Executive Summary
ESA	European Space Agency
FAA	Federal Aviation Administration
FAME	Frequency Agile Materials for Electronics
FAR	false alarm rate
FDM	frequency division multiplexing
FISRA	Federal Information Security Reform Act
FLANG	Florida Air National Guard

FPC2	Force Protection Command and Control
FQPSK	Feher's patented quadrature phase shift keying
FROST	Fast Readout Optical Storage Technology
FSO	Free-Space Optics
FTS	flight termination system
GaN	gallium nitride
Gbps	gigabyte per second
Gbyte	gigabyte
GE	General Electric
GEMS	Global Environmental MEMS Sensors
GEO	geosynchronous Earth orbit
GHz	gigahertz
GIG	Global Information Grid
GMPLS	Generalized Multi-Protocol Label Switching
GMSP	Global Multimission Support Platform
GMTI	Ground Moving Target Indication
GOTCHA	Goals, Objectives, Technical Challenges, and Approaches
GOTS	Government off the shelf
GPS	global positioning system
GPS-1	GPS Antenna System –1
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
HAA	high-altitude airship
HAIIS	High-Altitude Intercept Imaging System
HALO	High-Altitude Large Optics, High Altitude Laboratory
HAPS	High-Altitude Platform Station
HCC	Human-Centered Computing
HDTV	high-definition television
HPCS	High-Productivity Computing Systems
HRDV	high-resolution direct video
HYDICE	Hyperspectral Digital Imagery Collection Experiment
Hz	hertz
IATFF	Information Assurance Technology Framework Forum
IBDSS	Integrated Base Defense Security System
ibid.	ibidem, in the same place
ICBM	intercontinental ballistic missile
ICTS	International Consortium for Telemetry Spectrum
IDU	Intelligent Data Understanding
IF	information fusion
IFEA	information fusion technology
IMU	Inertial Measurement Unit
INACTS	Integrated National Aerospace Control Toolset
IP	internet protocol
IPTO	Information Processing Technology Office
IRIG	Inter-Range Instrumentation Group
IRSC	Intelligent Systems and Robotics Center
ISAT	Innovative Space-Based Radar Antenna Technology
ISI	inter-symbol interference

ISR	Intelligence, Surveillance, and Reconnaissance
ISS	International Space Station
ISTP	Integrated Space Transportation Plan
IULA	Incremental Upgrade of Legacy Systems
IWG	Interagency Working Group
JAMI	Joint Advanced Missile Instrumentation
JARSS	Joint Advanced Range Safety Systems
JITC	Joint Interoperability Test Command
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
JTRS	Joint Tactical Radio System
kbps	kilobit per second
KHz	kilohertz
km	kilometer
KSC	Kennedy Space Center
LAAS	Local Area Augmentation System (for GPS)
LAIR	large aperture infrared (optics)
LaRC	Langley Research Center
LASH	Littoral Airborne Sensor Hyperspectral
LCC	launch commit criteria
LEO	low Earth orbit
LIDAR	light detecting and ranging (like radar, but using a laser)
LLC	Limited Liability Corporation
LLCC	lightning launch commit criteria
LPI/LPD	low probability of intercept/low probability of detection
LPT	Low Power Transceiver
LRU	line replaceable unit
MANET	mobile ad hoc network technology
MARCONI	Mission Accredible Radio Connected Intranet
MARSS	previous name for Eastern Range Dispersion Assessment System
MB	megabyte
Mbps	megabit per second
MC2A	Multisensor Command and Control Aircraft
MC2C	Multisensor Command and Control Constellation
MCC	Mission Control Center
McSLAM	Mesoscale Coupled Sea, Land, and Air Model
MDA	Missile Defense Agency
MEGS	Missile End Game System
MEMS	micro electromechanical systems
MEO	medium Earth orbit
MFCW	multifrequency continuous wave (imaging radar)
MHz	megahertz
MIPAS	Michelson Interferometer for Passive Atmosphere Sounding
MoBIES	Model-Based Integration of Embedded Software
MOTR	multiple-object tracking radar
MPLS	multi-protocol label switching
ms	millisecond
MSFC	Marshall Space Flight Center

MSTCS	Multi-Service Target Control System
MTO	Microsystems Technology Office
NAI	National Aerospace Initiative
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NEST	Networked Embedded Software Technology
NETEX	Networking in Extreme Environments
NEXRAD	Next-Generation Radar
NGI	next-generation internet
NGLT	Next-Generation Launch Technology
NIAP	National Information Assurance Partnership
NIST	National Institute for Standards and Technology
NLE	no longer endanger
NLT	no longer terminate
NM	nautical miles
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
NRL	Naval Research Laboratory
NRZ	non-return to zero
NSF .	National Science Foundation
NSTISSI	National Security Telecommunications and Information Systems Security Instruction
OCACT	Ohio Consortium for Advanced Communications Technology
OCTAVE	Operationally Critical Threat, Asset, and Vulnerability Evaluation
ORS	operationally responsive spacelift
OSD	Office of Secretary of Defense
OSP	Orbital Space Plane
PARX	Plasma Wave Advanced Receiver
PCL	passive coherent locator
PCM/FM	pulse code modulated-frequency modulation
PCN	personal communication network
PDA	personal digital assistant
PDAS	Photo Data Analysis System
PIRANHA	Predator Infrared Airborne Narrowband Hyperspectral Combat Assessor
POD	probability of detection
PSCA	planning, scheduling, and coordinating of assets
PWR	power
QoS	quality of service
RAVE	Reconfigurable Automatic Virtual Environment
RCC	Range Commanders Council, Range Control Center
RCCS	Range Command and Control System
RECAP	Reconfigurable Aperture Program
RF	radio frequency
RISC	Reconfigurable Aperture Program
RKF	Rapid Knowledge Formation
RLV	reusable launch vehicle
ROCC	Range Operations Control Center
RSVP	Resource Reservation Setup Protocol

RTCP	Real-Time Control Protocol
RTLS	return to launch site
RTP	Real-Time Transport Protocol
SA	situational awareness
SABER	Sounding of Atmosphere Using Broadband Emission Radiometry
SAR	synthetic aperture radar
SATCOM	satellite communication
SATMS	Space and Air Traffic Management System
SBIR	Small Business Innovation Research
SCA	Software Communications Architecture
SCOPE	Small Communications Optical Package Experiment
SE	spectral efficiency
sec	second
serdes	serializer-deserializer
SERT	Space Solar Power Exploratory Research and Technology
SiC	silicon carbide
SIL	Space Information Laboratories
SIR-C	Shuttle Imaging Radar C
SLBM	submarine-launched ballistic missile
SLI	Space Launch Initiative
SLRSC	Space Lift Range Systems Contract
SMC	Space and Missile Systems Center
SME	subject matter experts
SN	space network
SNMP	simple network management protocol
SPADS	Spaceport Arrival and Departure Safety
SPO	Special Projects Office
SRI	Stanford Research Institute
SRLV	suborbital reusable launch vehicle
SRTM	Shuttle Radar Topography Mission
STAB	Steered Agile Beams
STARS	Space-based Telemetry and Range Safety
STK	satellite tool kit
STS	Space Transportation System (i.e., the Space Shuttle)
T&E	test and evaluation
TARDEC	Army Tank and Automotive Research Development and Engineering Center
TBD	to be determined
TCA	Transformational Communication Architecture
TCDL	Tactical Common Data Link
TCO	Transformational Communication Office
TCS	Transformational Communication System
TDM	time division multiplexing
TDMA	time division multiple access
TDRSS	Tracking and Data Relay Satellite System
TENA	Test and Training Enabling Architecture
TG	Telemetry Group
THOR	Tera Hertz Operational Reachback
TM	telemetry

TMATS	Telemetry Attributes Transfer Standard
TSPI	time-space position information
TT&C	tracking, telemetry, and commanding
TUSW	Theater Undersea Warfare Initiative
UAV	unmanned aerial vehicle
UCAV	Unmanned Combat Aerial Vehicle
UDS	Universal Documentation System
UHF	ultra high frequency
ULE-UAV	ultra-long-endurance UAV
USAF	United States Air Force
USD	Undersecretary of Defense
UUNET	Unix-To-Unix Network
UV	ultraviolet
UWB	ultra-wideband
VAD	Voice Activity Detection
VBITS	Vehicle-Based Independent Tracking Systems
VISA	Vertically Interconnected Sensor Arrays
VIVID	Video Verification of Identity
VOIP	voice-over internet protocol
VPN	virtual private network
w/i	within
WAAS	Wide Area Augmentation System (for GPS)
WACCM	Whole Atmosphere Climate Community Model
WDM	wavelength division multiplexing
WDSS-II	Wind Decision Support System
WFF	Wallops Flight Facility
WNN	wideband network waveform
WPAFB	Wright-Patterson Air Force Base, Ohio
WR	Western Range
WRC	World Radiocommunication Conference
WRF	weather research and forecast
XG	next-generation (DARPA program)
XML	eXtensible Markup Language

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